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Illinois Biomass Resources: Annual Crops and Residues; Canning and Food-Processing Wastes

Preliminary Assessment

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Preliminary Assessment

by

Antonios A. Antonopoulos

Energy and Mineral Resources Section
Energy and Environmental Systems Division

June 1980

Prepared for and Sponsored by
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FOREWORD

This preliminary assessment of the biomass potential in Illinois was prepared for the Illinois Institute of Natural Resources in response to the Institute's desire to explore the production and conversion of biomass to fuels and chemicals. Two main biomass resources have been evaluated in this investigation: (1) annual crops and their residues, and (2) canning and food processing wastes. In addition, three technologies for conversion of biomass to fuels were examined: (1) direct combustion to generate heat and electricity, (2) fermentation to yield ethanol for gasohol, and (3) gasification to produce methane. Use of biomass as a source of valuable chemicals (other than ethanol and methane) was also investigated. Finally, the environmental impacts and economic consequences of producing and converting biomass to fuels, electricity, and chemicals in Illinois were analyzed.

ACKNOWLEDGMENTS

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ILLINOIS BIOMASS RESOURCES: ANNUAL CROPS AND RESIDUES; CANNING AND FOOD-PROCESSING WASTES

Antonios A. Antonopoulos

ABSTRACT

Illinois, a major agricultural and food-processing state, produces vast amounts of renewable plant material having potential for energy production. This biomass, in the form of annual crops, crop residues, and food-processing wastes, can be converted to alternative fuels (such as ethanol) and industrial chemicals (such as furfural, ethylene, and xylene). The present study provides a preliminary assessment of these Illinois biomass resources, including (a) an appraisal of the effects of their use on both agriculture and industry; (b) an analysis of biomass conversion systems; and (c) an environmental and economic evaluation of products that could be generated from biomass. It is estimated that, of the 39 x 10^6 tons of residues generated in 1978 in Illinois from seven main crops, about 85% was collectible. The thermal energy equivalent of this material is 658 x 10^6 Btu, or 0.66 quad. And by fermenting 10% of the corn grain grown in Illinois, some 323 million gallons of ethanol could have been produced in 1978. Another 3 million gallons of ethanol could have been produced in the same year from wastes generated by the state's food-processing establishments. Clearly, Illinois can strengthen its economy substantially by the development of industries that produce biomass-derived fuels and chemicals. In addition, a thorough evaluation should be made of the potential for using the state's less-exploitable land for the growing of additional biomass.

1 INTRODUCTION

1.1 ENERGY SUPPLY AND DEMAND AND THE BIOMASS POTENTIAL

The recent scarcity and skyrocketing prices of petroleum-based fuels have motivated government officials and researchers to investigate every possible source of fuel production. Each day the United States imports nearly 8.5 million barrels of crude oil, and each day will send overseas more than $238 million (based on the cost of foreign crude oil at $28 per barrel [Time, 1980]). And the price of gasoline at the pump could reach $1.50 per gallon by the end of 1980 (U.S. News and World Report, 1980). While energy conservation is being advocated and practiced, we continue to need more sophisticated and rapid exploration of alternative energy and fuel sources.

One of these potential sources is biomass, specifically the material from plants of many types. Biomass energy is actually solar energy that has been captured and stored by the photosynthesizing biomass and which in turn can be consumed and utilized by nonphotosynthesizing organisms. Each dry pound of plant biomass contains an average of 7,500 Btu, or more than one-half the energy in one pound of coal. From an economic point of view, the first priority in using biomass is the fulfillment of human food needs; second is the production of valuable feed, fiber, and chemicals; and third is its use for energy and fuel production. Residual and waste biomass, which is useful for the third priority, is both an economically and environmentally sound source of fuel and energy. It is renewable, clean, and readily convertible. The amount of residual biomass in the United States is enormous; ten major crops generate more than 400 million tons of residues annually, 20% of which may be available for fuel production (Barber, 1979). If biomass fuels can meet a small percentage of the energy consumed every year in the United States (in 1979, energy consumed was 78.197 quads* [Monthly Energy Review, 1980]), a significant contribution will be made to the solution of the nation's energy problems. Besides the direct use of biomass for energy and fuel production, biomass can be used to produce chemical and industrial feedstock, thus saving additional energy and petroleum.

The state of Illinois (Figure 1.1) is characterized by highly productive land that is influenced by a favorable combination of ecological, economic, and sociopolitical factors. Because of today's energy problems, an evaluation of the potential of Illinois biomass resources for fuel and chemicals production is vital. This study attempts to provide a preliminary assessment of the potential of annual crops and their residues and that of canning and food processing wastes.

1.2 PURPOSE AND APPROACH

Crops and their residues in Illinois are important biomass resources for alternative energy and industrial-chemical production, as are the wastes from canning and food processing operations. As both an industrial and agricultural state with a high demand for energy, Illinois can substantially strengthen its economy by further development of industries that produce biofuels (such as gasohol) and biomass-derived chemicals. However, mismanaged

*One quad = 10^{15} Btu.

Fig. 1.1. Counties and Major Cities of Illinois

exploitation of the state's agricultural resources in order to generate more energy and chemicals could have serious adverse economic and environmental impacts. Furthermore, the additional demand for grain for fuel production could increase food prices. For these reasons, this preliminary study has been undertaken to identify and evaluate the economic and environmental consequences of increasing biomass-energy utilization in Illinois. There are three major objectives of the study: (1) an evaluation of the state's biomass resources, (2) an economic and environmental analysis of biomass conversion systems, and (3) an economic and environmental assessment of industrial products that could be obtained from renewable biomass resources.

Evaluation of Illinois biomass resources focuses on: the production of annual-crop biomass and the availability of canning and food processing wastes; their economic, energy, and chemical-feedstock values; the environmental effects of extensive residue removal from fields; the need for additional or alternate crop management practices; and the use of less exploitable lands for biomass production.

Analysis of biomass conversion to fuel and energy includes assessment of the near-term energy potential of crop biomass and of canning and food processing wastes to satisfy part of Illinois' energy requirements, with emphasis on direct combustion, liquid-fuel production (ethanol), and gas-fuel production (methane). The analysis characterizes these technologies and evaluates their environmental impacts and economic consequences.

Assessment of biomass-derived chemicals and feedstock for industries includes technology characterization and environmental and economic implications that arise during utilization of biomass for industrial purposes.

Statistical information for this work relies heavily on the U.S. Census of Agriculture (U.S. Department of Commerce), Agricultural Statistics (U.S. Department of Agriculture), Illinois Agricultural Statistics (Illinois Department of Agriculture), U.S. Census of Manufactures (U.S. Department of Commerce), and other sources. Estimates, when necessary, were made according to available information and the author's experience. Several numerical factors that were employed to compute needed information have been selected from the literature and adapted and/or modified to suit conditions in Illinois. The appendix contains tables that show, by county, biomass potential from annual crops, crop residues, and canning and food processing wastes.

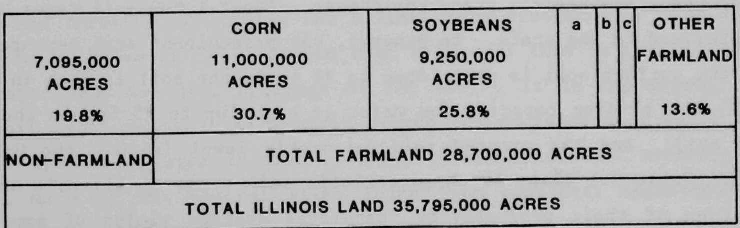
2 THE AGRONOMIC PROFILE OF ILLINOIS

2.1 INTRODUCTION

Illinois lies some 650 miles west of the Atlantic coast and 470 miles north of the Gulf of Mexico; it extends in latitude from 37° to 42° 30' N and in longitude from 87° to 91° 30' W. The state is favored with a combination of superior soils, well-distributed annual precipitation, and a temperate climate that contributes to highly productive agriculture. Agriculture in Illinois is an intensive industry. While total farm area has declined by about 2.5 million acres since 1957, the state's crop production index has risen 79% during the same period. Today Illinois ranks first among the 50 states in soybean production and second in corn acreage. Its cash receipts from crops classify it second among states, while its livestock income ranks eight in the nation. Less than 450,000 people now live and work on 107,000 farms that occupy 28,700,000 acres of the state's land; this means that while only one in 25 inhabitants is a farm resident, 80.2% of the state is in farmland. Figure 2.1 depicts the acreage and percentage of land utilization during 1978.

2.2 CLIMATE

Illinois stretches some 380 miles north to south, so that there are major climatic differences throughout the state. The climate is generally humid and is characterized by cold winters and warm summers; the northern



[a] Pasture: 1,850,000 acres (5.2%)

[b] Wheat: 1,000,000 acres (2.8%)

[c] Hay: 760,000 acres (2.1%)

Fig. 2.1. Land Utilization in Illinois (Source: Illinois Dept. of Agriculture, 1979)

counties are somewhat cooler and drier than those in the south. The climatic elements are subject to frequent, but brief, fluctuations. Temperature extremes range from below zero to above 90°F. Total annual precipitation averages 32 to 48 in. (the higher amounts occur in the south, mostly during winter and early spring), with a well distributed rainfall of about 21 to 24 in. during the April-September period. Annual snowfall ranges from about 10 in. (in southern counties, which are snow covered about 15 days each year) to 30 in. (in northern counties, where snow covers the ground for an average of about 50 days). The 30 to 50 thunderstorms per year are occasionally accompanied by hailstorms, high winds, and tornadoes. The frost-free period in southern counties is about 210 days, while that in the north is less than 155 days.

2.3 SOILS

Illinois land has been farmed for only about 150 years, and its soils are young and rich. The strong impacts of the four great glaciers that spread over Illinois in the past 600,000 years, the loess deposits (up to 25 ft deep in some areas), together with the remains of the native vegetation, have formed rich soils. The pioneers found tall prairie grass covering more than 62% of Illinois and forests in most of the remaining areas. The vigorous annual grasses enriched many inches of the prairie soil with organic matter (O.M.), in contrast to the few inches of soil supplied with O.M. from the residues of slow-growing forest trees.

Today, Illinois agriculture is confined to the prairie soils that have evolved under the prairie grass enrichment. About 1,000 soil types have been characterized in the state. In general, the predominant soil texture is silt loam, the surface soil is deep (down to 20 in.), the soil is rich in O.M. (up to 6%), the holding capacity for water is high (up to 15 in. in the upper 5 ft of soil), and the cropped soil is mostly level (within the 0-2% slope class). Table 2.1 lists 14 characteristic soil types of Illinois and, as an indication of their productivity, tabulates average yields of some typical crops.

The most fertile soil types in Illinois are the Muscatine and Flanagan, which are dark, deep prairie soils confined to north central and northwestern Illinois; these soils are silt loams with thick topsoil and high O.M.

Table 2.1. Fourteen Characteristic Illinois Soil Types and Their Productivity for Five Typical Crops

Soil Type	Corn	Soybeans	Wheat	Oats	Alfalfa-Mixed Hay (Tons/Acre)
	Bushels/Acre				
Muscatine	110	40	48	75	5.0
Flanagan	108	39	48	73	5.0
Sable	100	39	44	66	4.7
Drummer	100	39	44	66	4.7
Clinton	80	29	37	55	3.9
Hosmer	70	28	36	45	3.3
Elliott	88	34	40	65	4.1
Cisne	78	30	35	53	3.5
Hagener	65	25	25	45	2.8
Grantsburg	69	26	34	--	3.3
Lawson	96	38	41	63	4.6
Belknap	73	29	33	--	3.7
Alford	87	30	41	54	4.0
Fayette	91	31	40	66	4.2

SOURCE: Aldrich, 1965.

(about 6%) and available nitrogen content. Northeastern Illinois is characterized by soils that are more compact and higher in clay content than those in central and northwestern areas; soils here are a mixture of both prairie and forest origin, with the Elliott type predominant. The southern one-fourth of Illinois is a claypan with a subsoil that is rich in clay and thus responsible for poor drainage of the soil. It is represented by the Cisne soil type, which is of prairie origin and contains only small amounts of O.M. The floodplains of most Illinois rivers consist of bottomlands and terraces made of the neutral silty loams from erosional deposits and are characterized as Lawson (nearly neutral) and Belknap (usually acid, occurring in the southern floodplains) types. Adjacent to the floodplains are deep loess deposits, formed in the forest floors, that characterize the Fayette and Alford soil types. Sandy soils can be found in a few areas; these are mainly sandy loams that are relatively rich in O.M., poor in moisture, and represented by the Hagener type. The stream sites and the steep slopes are mostly covered with forest soils such as the Clinton and Hosmer types that are poor in O.M. and in N, P, and K when compared to the prairie soils.

Illinois farmers apply the highest tonnages of fertilizer in the nation, but use less fertilizer per acre than farmers in many other states. The nitrogen content of the Illinois soils varies widely, and most of the prairie soils contain twice the nitrogen found in forest soils. The same is true for phosphorus and potassium contents of the soil, because the richer the soil in O.M., the more phosphorus and potassium are available to plants. Illinois soils need lime, since large areas show a pH below the neutral point. It is characteristic that the limestone tonnage spread today on Illinois soils surpasses that of any other state.

2.4 CROPS

The major field crops of Illinois are corn, soybeans, wheat, oats, and hay; the minor crops include barley, rye, sorghum, and potatoes. Table 2.2 lists acreages harvested, yield per acre, and total production of field crops for 1970-1978, while Figure 2.2 shows the distribution of corn, soybeans, wheat, and oats production for 1978. The appendix contains crop data by county for 1974 and 1978.

Corn is the chief Illinois crop and ranks second nationally in acreage. Its harvested value is close to one-half of all crops in the state. Ninety-five percent of the acreage is harvested for grain, and the rest is utilized for silage, green chop, and dry fodder, or for grazing. For 1978, the total harvested corn area was about 11 million acres; this includes nearly 235,000 acres that were harvested for silage and produced 3.64 million tons, as well as 25,000 acres of corn that were hogged down, grazed, or harvested for forage. The 10.7 million acres of corn harvested for grain in 1978 produced nearly 1,200 million bu, with an average yield of 111 bu/acre for the entire state and a value of $2,561 million (season average price per bu, $2.15; value of production per acre, $238.65). Corn cash receipts by Illinois farmers were second only to those for soybeans, and corn provided 27% of the total farm income in 1978. Farmers received $1,626 million from corn sales in 1978, about 10% less than in 1976. The highest record of corn yield per acre and total production during the period 1924 to 1978 was in

Table 2.2. Acreage, Yield, and Production of the Major Field Crops of Illinois, 1970-1978

	CORN (grain)			SOYBEANS		
Year	Harvested Acres (1,000)	Yield per Acre (Bushels)	Production (1,000 Bushels)	Harvested Acres (1,000)	Yield per Acre (Bushels)	Production (1,000 Bushels)
1970	9,940	74.0	735,560	6,800	31.0	210,800
1971	10,070	106.0	1,067,420	7,150	33.0	235,950
1972	9,225	110.0	1,014,750	7,520	34.5	259,440
1973	9,530	103.0	981,590	8,930	31.5	281,295
1974	9,900	83.0	821,700	8,440	24.0	202,560
1975	10,810	116.0	1,253,900	8,320	36.0	299,520
1976	11,590	107.0	1,240,130	7,560	33.0	249,480
1977	11,080	105.0	1,163,400	8,850	38.0	336,300
1978	10,730	111.0	1,191,030	9,190	33.0	303,270
	WHEAT			OATS		
1970	1,030	37.0	38,110	612	56.0	34,272
1971	1,000	46.0	46,000	580	60.0	34,800
1972	1,200	45.0	54,000	440	63.0	27,720
1973	1,300	30.0	39,000	430	46.0	19,780
1974	1,730	30.0	51,900	480	51.0	24,480
1975	1,730	39.0	67,470	445	56.0	24,920
1976	1,850	39.0	72,150	380	59.0	22,420
1977	1,570	43.0	67,510	340	61.0	20,740
1978	930	38.0	35,340	275	56.0	15,400

SOURCE: Illinois Dept. of Agriculture, 1976 and 1979.

1975, when 1,254 million bu of corn grain were produced for an average yield of 116 bu/acre. McLean County is the leading corn producer, with 47.7 million bu in 1975 and 45.1 million bu in 1978. Important corn-producing counties are listed in Table 2.3. As an indication of planting dates for Illinois corn, one-third of the planting in 1978 occurred at the beginning of May, and by early June about 92% of planting was completed. By September 1, about 50% of the acreage was mature, and the entire crop had matured by the end of September. Harvesting began in mid-September, was largely completed

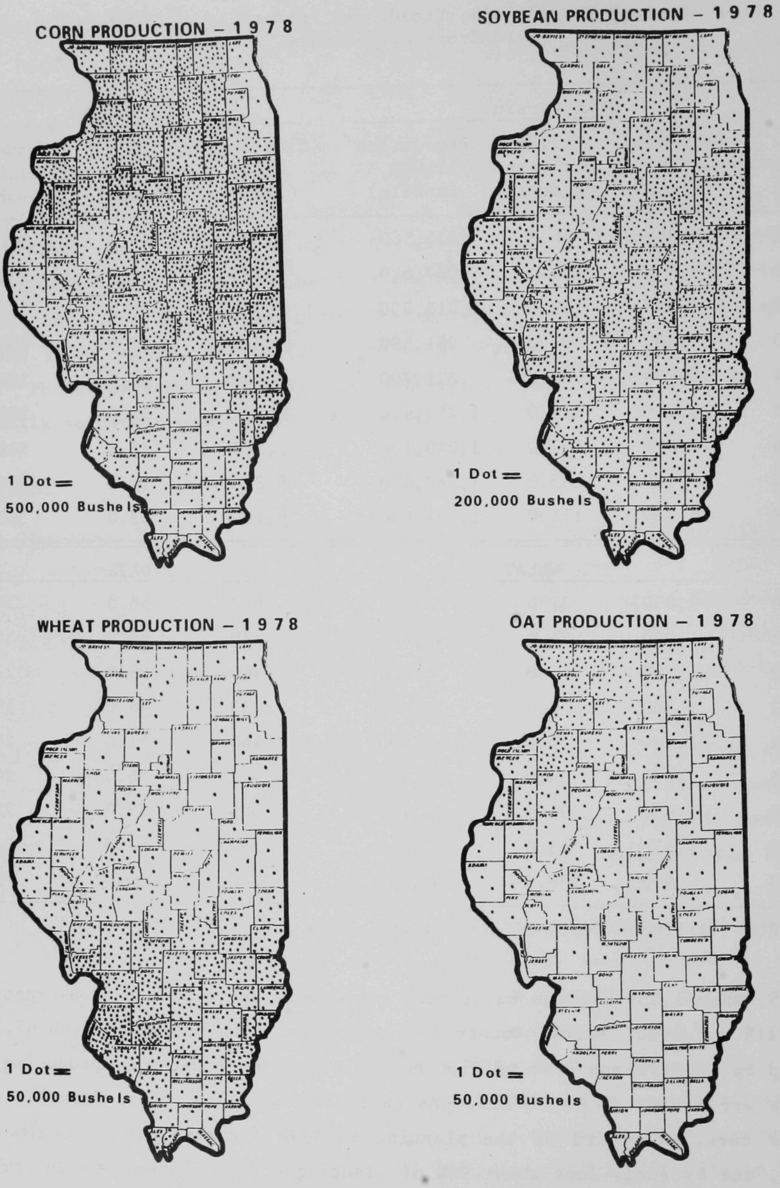


Fig. 2.2. Distribution of Major Crops in Illinois, 1978 (Source: Illinois Dept. of Agriculture, 1979)

Table 2.3. Leading Counties in Corn Production, 1974 and 1978

County	1974 Production (Bushels)	1974 Yield (Bushels/Acre)	1978 Production (Bushels)	1978 Yield (Bushels/Acre)
McLean	32,035,000	91.6	45,145,200	125.3
Champaign	26,724,500	97.6	38,062,600	132.7
Iroquois	27,108,400	89.5	36,899,200	112.3
La Salle	25,254,700	85.3	34,623,200	110.8
Livingston	21,585,500	79.3	34,017,500	119.4
Bureau	20,294,100	84.1	32,193,700	117.8
Henry	17,135,900	81.1	28,730,700	117.8
Vermilion	18,313,900	89.5	25,981,800	119.4
Whiteside	13,736,700	77.0	24,774,200	110.8
Ogle	12,973,100	68.9	25,644,400	117.8
De Kalb	14,486,800	80.3	25,384,200	125.7
Lee	14,643,100	76.0	24,596,000	117.8
Knox	15,090,800	96.8	22,004,400	119.8
Sangamon	20,818,900	106.8	22,631,300	112.8
Tazewell	14,421,200	88.5	21,204,100	117.1
Warren	16,901,600	106.0	20,533,700	120.9
Logan	16,163,400	94.6	20,442,000	111.0
Kankakee	12,409,500	69.1	20,401,500	113.3
Macon	13,826,000	94.6	19,598,600	123.3
Piatt	12,718,500	91.5	19,192,200	135.7

SOURCE: Illinois Dept. of Agriculture, 1976 and 1979.

in October, and the remaining 10% was harvested in November. About 97% of the corn is planted by drilling and in rows spaced 36 in. apart. The fertilizing regime for 1978 was as follows: 140 lb nitrogen plus 84.6 lb phosphorus plus 98.8 lb potassium per acre of corn, mostly applied at or before seeding.

Illinois soybean production today is the highest in the nation. Soybeans provide the largest cash income to Illinois farmers, accounting for 33% (1978) of total receipts and contributing one-half of the cash income from all crops. In 1978, about 9.2 million acres produced 303 million bu of soybeans (33 bu/acre) that were valued at $925 million ($3.05 was the season average price per bu). The record high soybean yield per acre and total production for 1919-1978 was in 1977, when 336 million bu were produced at an average yield of 30 bu/acre. As it is for corn, McLean County is also the leader in soybean production, with 10.5 million bu in 1978. Other important soybean producing counties are listed in Table 2.4. The most common soybean variety in Illinois is the Williams (35% of the acreage in 1978), followed by Amsoy (9%), Woodworth (8%), Corsoy (7%), Wells (6%), Wayne (6%), and several other varieties. In 1978, about 90% of the acreage was planted between the end of May and June 20. In the same year, 90% of the podding was mature by August 31, and the harvesting started in mid-September and finished by the end of October. As an average, the soybean rows are spaced 30 in. apart. The average amount of fertilizers applied in 1978 was as follows: 13.8 lb nitrogen + 50.3 lb phosphorus + 84.8 lb of potassium per acre of soybeans, applied before seeding.

Wheat is the third important crop in Illinois; in 1978 it accounted for 2% of the total cash farm income, or $106.5 million. Basically, wheat acreage in the state is stabilized at about one million acres. Since 1866, the highest yield was in 1971 with 46 bu/acre, and the record high production was in 1976 with 72.15 million bu. In 1978 (preliminary census), 930,000 acres produced 35.34 million bu of grain wheat for a yield of 38 bu/acre. For the same year, St. Clair County led the state in wheat production with 2.1 million bu from 49,000 acres, while the highest yield was obtained in Stephenson County with 46.5 bu/acre. Table 2.5 tabulates the twenty leading counties in wheat production for 1978. Only winter wheat is grown in Illinois, most of which consists of soft varieties (91% in 1979). The most commonly grown varieties are Arthur 71 (34%), Abe (22%), and Arthur (16%). During 1978, wheat seeding started at the end of September and was completed just past the middle of October, while harvesting started in mid-June and was finished by the end of July. Most of the planted acres (1978) received nitrogen, three-quarters received phosphorus, and about one-half had potassium applied, at rates per acre of 56.8 lb nitrogen + 69.2 lb phosphorus + 68.8 lb potassium.

Oats is the fourth important crop in Illinois. The 275,000 acres harvested in 1978 produced 15.4 million bu of grain oats (56 bu/acre), and provided farmers with $19.25 million. Because of corn and soybean profitability,

Table 2.4. Leading Counties in Soybean Production, 1974 and 1978

County	1974 Production (Bushels)	1974 Yield (Bushels/Acre)	1978 Production (Bushels)	1978 Yield (Bushels/Acre)
McLean	6,909,700	27.4	10,531,900	39.9
Champaign	6,565,700	27.1	10,000,300	39.2
Livingston	6,792,100	25.2	9,686,000	35.7
Iroquois	6,877,800	27.1	9,347,500	34.7
La Salle	6,503,300	29.2	7,726,900	33.9
Vermilion	4,219,900	24.2	7,640,800	36.7
Sangamon	4,485,500	27.6	7,424,100	39.1
Christian	4,140,100	24.6	6,565,800	37.1
Macoupin	3,953,700	27.6	5,571,100	31.7
Logan	3,620,500	25.5	5,455,100	38.4
Edgar	3,287,200	23.7	5,425,200	38.2
Shelby	3,161,800	22.7	5,418,200	34.7
Montgomery	3,171,600	23.6	5,1511700	30.7
Macon	3,083,500	23.5	5,043,900	37.9
Hancock	3,464,400	25.6	4,993,300	35.2
Ford	3,249,900	25.2	4,855,900	36.2
Kankakee	2,996,500	24.2	4,750,700	32.8
Douglas	2,546,400	26.7	4,699,300	38.2
Piatt	2,539,500	23.3	4,375,400	38.7
Coles	2,765,200	27.7	4,355,400	38.2

SOURCE: Illinois Dept. of Agriculture, 1976 and 1979.

oats acreage has rapidly declined in recent years. In 1970 some 612,000 acres produced 34.3 million bushels, or twice the production of today. For 1978, Henry County was the chief producer of oats in the state, as shown in Table 2.6.

Another significant annual crop in Illinois is sorghum; in 1978, this crop covered 68,000 acres and produced 4.6 million bu of grain. At an average season price of $1.79/bu, sorghum provided a total production value of $8.3 million. At the same year, another 7,000 acres were harvested for sil-

Table 2.5. Leading Counties in Wheat Production, 1974 and 1978

County	1974 Production (Bushels)	1974 Yield (Bushels/Acre)	1978 Production (Bushels)	1978 Yield (Bushels/Acre)
St. Clair	1,919,700	32.4	2,113,100	43.1
Washington	1,614,900	26.3	1,937,600	42.1
Madison	2,354,200	34.8	1,563,100	37.2
White	1,212,600	28.2	1,279,300	41.3
Monroe	1,114,800	29.3	1,254,100	41.1
Montgomery	1,157,200	31.7	1,206,900	37.7
Randolph	1,194,100	26.3	1,134,800	36.6
Macoupin	1,549,100	33.7	1,113,400	41.2
Clinton	1,011,600	25.3	1,086,100	38.1
Marion	1,295,000	26.5	1,047,000	37.4
Fayette	1,383,200	28.5	954,400	32.9
Shelby	1,285,100	31.6	933,400	38.9
Jefferson	908,600	26.2	846,000	41.3
Effingham	1,048,100	30.6	816,700	38.9
Bond	1,070,700	29.7	803,400	35.7
Hamilton	882,400	26.2	755,400	39.8
Clay	800,000	22.4	753,900	35.9
Wayne	1,105,600	22.2	750,400	35.7
Jersey	744,500	35.8	735,200	43.2
Crawford	1,020,200	32.6	637,000	36.4

SOURCE: Illinois Dept. of Agriculture, 1976 and 1979.

age, producing 81,000 tons, while 5,000 more acres were harvested for forage. Generally, the acreage for sorghum is stabilized at about 70,000 acres, although in 1970 it was 20,000 acres and in 1971 it increased to 170,000 acres. The ten important sorghum producing counties are listed in Table 2.7.

In 1978, nearly 16,000 acres of rye were harvested, producing 368,000 bu with a value of $846,000, and 7,000 acres of barley were harvested and produced 252,000 bu valued at $441,000. Cass County was the leader in rye production for 1977, and Lake County led in barley production for the same

Table 2.6. Leading Counties in Oat Production, 1974 and 1978

County	1974 Production (Bushels)	1974 Yield (Bushels/Acre)	1978 Production (Bushels)	1978 Yield (Bushels/Acre)
Henry	1,692,000	51.4	1,378,000	61.5
Stephenson	1,280,700	50.4	883,300	58.5
Jo Daviess	900,300	48.4	858,500	56.5
Ogle	1,282,700	53.4	695,600	57.5
Whiteside	827,700	48.4	653,600	60.5
Bureau	896,700	57.5	570,100	60.0
Carroll	1,264,600	57.5	559,800	56.0
McHenry	860,100	57.7	482,800	57.5
Lee	781,700	57.5	452,400	58.0
Knox	609,800	49.6	426,200	60.9

SOURCE: Illinois Dept. of Agriculture, 1976 and 1979.

Table 2.7. Leading Counties in Sorghum Grain Production, 1974 and 1978

County	1974 Production (Bushels)	1974 Yield (Bushels/Acre)	1978 Production (Bushels)	1978 Yield (Bushels/Acre)
Pulaski	145,100	50.0	417,400	73.2
Washington	232,700	50.0	350,400	76.2
Clinton	100,900	48.0	220,900	76.2
Bond	134,700	42.8	197,300	74.5
Johnson	120,100	50.0	190,700	61.5
Randolph	130,100	50.0	190,400	63.5
Monroe	100,900	48.0	159,400	66.4
Massac	101,200	48.2	145,000	69.0
Madison	96,300	43.8	134,000	74.4
Perry	86,500	48.1	133,300	63.5

SOURCE: Illinois Dept. of Agriculture, 1976 and 1979.

year. Average rye acreage since 1970 has declined by nearly one-third; that for barley has dropped by about one-half. Tables 2.8 and 2.9 list the ten leading counties in rye and barley production.

Illinois produces an enormous amount of hay each year. For 1978, production of alfalfa hay was 2.8 million tons from 760,000 acres, accounting for a total production value of $147 million. Production of other hay (mostly red clover, timothy, and lespedeza) was 897,000 tons from 460,000 acres, for a total value of $48 million. The record hay production -- more than 5 million tons - occurred in 1956, while the highest yield -- 3 tons/acre -- was obtained in 1977. The acreage devoted to hay production is stabilized at the level of 1.2 million acres, with alfalfa occupying 0.75 million acres. Nearly 50,000 acres were harvested for hay-seed production in 1978, producing 3.4 million lb of red clover seed ($2,142,000), 0.77 million lb of timothy seed ($270,000), and 0.44 million lb of lespedeza seed ($145,0000. Table 2.10 shows the ten leading counties, in 1978, in Illinois hay production. During 1978, the first cut of alfalfa started in May and finished in June, the second started at the end of May and finished in mid-August, and the third began in early August and was completed at the end of September. For other hays, the cut began in mid-May and ended in July.

In summary, the use of better varieties and the application of continuously improving soil and crop management practices, combined with the state's excellent soils and favorable climate, promise that yields will keep rising. Figure 2.3, based on research by the Illinois Cooperative Crop Reporting Service, depicts the regression lines that represent the yield trends of the five major crops in the state for 1939 through 1977. The corresponding equations are:

corn, $y = 38.4 + 1.77x$; wheat, $y = 16.6 + 0.68x$; soybeans, $y = 19.5 + 0.37x$; oats, $y = 35.7 + 0.67x$; and hay, $y = 2.0 + 0.035x$;

where:

$x = 39$ years from 1939 through 1977.

Figure 2.3 shows that, during the 39-year period, yields for corn were nearly triple (2.8 times), for wheat more than double (2.6 times), and for soybeans, oats, and hay, the yields increased more than 50% (1.6, 1.7, and 1.7 times more, respectively).

Table 2.8. Leading Counties in Rye Production, 1974 and 1977

County	1974 Production (Bushels)	1974 Yield (Bushels/Acre)	1977 Production (Bushels)	1977 Yield (Bushels/Acre)
Cass	14,300	17.9	14,700	22.6
Fayette	3,600	18.0	14,600	24.3
Tazewell	17,500	17.5	10,900	21.8
Montgomery	5,400	18.0	9,300	23.3
Randolph	900	18.0	9,000	22.5
Macoupin	4,500	18.0	8,900	25.4
Jasper	2,900	19.3	8,800	22.0
Madison	5,100	17.0	8,200	23.4
Carroll	5,800	23.2	7,400	24.7
Jersey	7,200	18.0	7,300	24.3

SOURCE: Illinois Dept. of Agriculture, 1976 and 1979.

Table 2.9. Leading Counties in Barley Production, 1974 and 1978

County	1974 Production (Bushels)	1974 Yield (Bushels/Acre)	1978 Production (Bushels)	1978 Yield (Bushels/Acre)
Lake	33,900	42.4	25,800	43.0
Stephenson	7,700	38.5	15,400	44.0
Randolph	25,100	31.4	13,100	43.7
McHenry	47,500	43.2	12,900	43.0
Montgomery	8,200	32.8	12,600	42.0
Fulton	3,400	34.0	11,900	39.7
Hancock	3,400	34.0	11,900	39.7
Monroe	25,800	32.3	10,800	43.2
St. Clair	15,000	33.3	8,400	42.0
Henry	7,700	38.5	8,300	41.5

SOURCE: Illinois Dept. of Agriculture, 1976 and 1979.

Table 2.10. Leading Counties in Hay Production, 1974 and 1978

County	1974 Production (Bushels)	1974 Yield (Bushels/Acre)	1978 Production (Bushels)	1978 Yield (Bushels/Acre)
Stephenson	220,100	3.49	224,800	3.81
Jo Daviess	186,000	3.44	210,700	3.76
McHenry	115,600	3.23	114,400	3.69
Carroll	90,000	3.40	106,200	3.71
Ogle	78,500	3.00	99,100	3.71
Pike	82,000	2.83	88,800	3.04
Henry	84,200	3.10	88,600	3.66
Winnebago	65,900	3.30	83,900	3.76
Adams	60,200	2.13	78,900	2.63
Mercer	63,900	3.20	77,400	3.37

SOURCE: Illinois Dept. of Agriculture, 1976 and 1979.

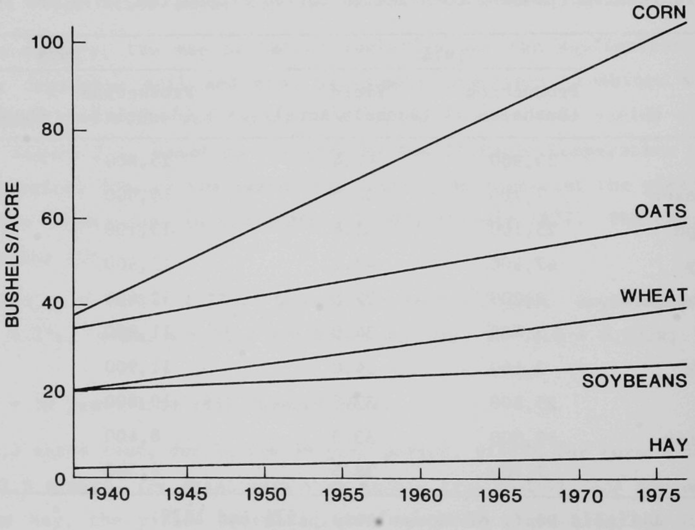


Fig. 2.3. Yield Trends of Main Crops in Illinois, 1939-1977
(Source: University of Illinois, 1978)

Substantial yield increases were made since the mid-1960s due to the application of a highly developed agricultural technology that included the use of improved varieties, the use of more effective pesticides and fertilizers, the employment of more efficient machinery, and the growth of more plants per acre.

Under given soil and climate conditions, the application of highly improved crop management is the key to successful crop production. In Illinois, this consists of: optimum soil drainage; maintenance of soil pH to 6.0 for grain production; availability of nearly 50 lb of phosphorus + more than 240 lb of potassium + nearly 175 lb of nitrogen as an average per acre; return of crop residues to soil; proper pest control; timely and suitable tillage, planting, and harvesting operations; and reduction of soil erosion to a minimum.

3 ANNUAL CROP RESIDUES

3.1 INTRODUCTION

In recent years many investigators have recommended the intensive use of annual-crop residues for energy and fuel production. Such use, however, involves several inherent problems that should be solved before utilizing annual-crop residues for energy and fuel purposes. These include generation, collection, transportation, storage, conversion to energy and fuels, soil fertility and erosion, environmental issues, economic consequences, energy balance, and even sociopolitical and institutional matters.

For centuries the residues left after harvesting and processing have been used to maintain soil fertility and integrity, feed animals, heat buildings, and supply fiber material. In addition to these uses, crop residues are potential sources of energy and feedstock for industry. The main solid constituent of crop residues is lignocellulose which, in direct combustion, can release more than 7,500 Btu/lb. On the other hand, cellulose from crop residues is a source of many useful industrial products such as rayon and cellulose acetate for plastics, films, and textiles; hexoses for ethanol (used in gasohol), glycerol, and acetic, butyric, and lactic acids; monosaccharides for anhydro sugars, etc. and methanol, methane, ammonia, and many more useful chemicals. Therefore, since today more than ever before we need energy and industrial products, we are well justified in studying comprehensively the production and utilization of crop residues.

It was estimated that nearly 380 million dry tons of crop residues were generated in the United States during 1978 (Ashare et al., 1979). Most of this is from cereal crops, corn, and soybeans. Additional residues are accumulated from the packing, processing and canning of vegetables, nuts, and grains. Hay and forage crops are not usually characterized as residue sources, since they are used entirely as animal feed. Nearly 40% of crop residue is made up from cereal straws, 25% from corn, 22% from soybeans, and 1% from other sources (packing, processing, canning, storage, etc.). Figure 3.1 shows the projected residue production for five U.S. crops. As shown in this figure, corn, wheat and soybean residues are and will continue to be the main sources, while residues from sorghum and oats will continue to be of lesser importance. As noted by Ashare et al. (1979), the highest density of

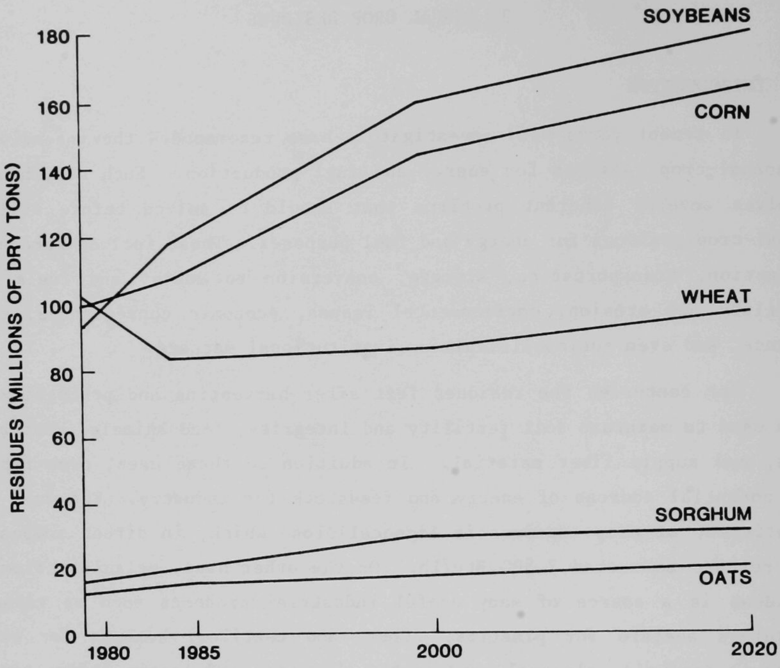


Fig. 3.1. Projected Estimates for Residues of Five U.S. Crops, 1980-2020

residues is generated in the corn belt where, on the average, nearly two tons of residues per acre are produced. It is obvious that Illinois is favored with a high yield of crop residues and, consequently, is a major potential source of energy and chemicals from biomass.

3.2 CROP-RESIDUE ASSESSMENT APPROACH

Most studies involving estimates of crop residues have followed indirect procedures. For example, based on the grain production of corn, the amount of residues generated is estimated as a product of the grain production multiplied by a residue factor (f_r). It is obvious that for general purposes this methodology is sound but that its accuracy depends upon the determination of the residue factor. This factor is directly related to several parameters such as the variety of the crop, soil and other ecological effects, time of planting and harvesting, and method of harvesting. It would appear to be more appropriate to directly assess crop-residue production by local sampling and weighing, but this is a tedious and time-consuming process. Basically, a well-chosen residue factor is a necessity and is the key to accurate estimation.

The following factors adapted from existing literature (Stanford Research Institute, 1978) have been employed in this preliminary analysis of Illinois crop residues:

1. Residue factor, which is the multiplier used to estimate crop residues (by multiplying crop production by this factor);
2. Residue collectibility factor, which expresses the actual collectible percentage of crop residues produced;
3. Wasted residue factor, which symbolizes the percentage of collectible crop residues that does not serve any economic purpose and is either disposed of or returned to the land;
4. Dry weight factor, which expresses the actual dry weight percentage of a residue unit;
5. Residue seasonality factor, which shows the available residue percentage in one season (quarter) of the year;
6. Energy equivalent factor, which is the Btu content (as a thermal equivalent) in one unit of crop residues;
7. Conversion factor from bushels to tons; and
8. Dollar-value factor, which refers to the economic value of a dry-residue unit in the field (uncollected).

Table 3.1 lists the factors employed in estimating the potential of annual-crop residues in Illinois. It should be emphasized that all these factors need a comprehensive revision to actually represent the Illinois situation.

Table 3.2 shows the costs of certain annual crop residues in Illinois as estimated by Stanford Research Institute investigators (1978), on which our calculations were based for a preliminary determination of crop residue values.

Table 3.1. Conversion Factors Employed in Estimated Crop Residue Potential in Illinois, 1978

Crop Residues	Residue Factor[a]	Collect-ibility Factor[a]	Wasted Residue Factor[b]	Dry Weight Factor[c]	Conversion Bushels to Tons[d]	Energy Equivalent (10^6 Btu/Dry Ton)[e]	Value in Field ($/Dry Ton)[f]
Corn Grain	1.10	0.90	0.45	0.53	0.028	16.8	28
Soybeans	2.14	0.80	1.00	0.85	0.030	16.8	22
Wheat	2.53	0.85	0.99	0.90	0.030	16.8	15
Oats	3.01	0.85	0.75	0.90	0.016	16.8	17
Sorghum Grain	1.57	0.90	0.40	0.40	0.028	16.8	28
Barley	2.50	0.85	0.99	0.91	0.024	16.8	17
Rye	2.50	0.85	0.99	0.72	0.028	16.8	15

[a]Adapted from Stanford Research Institute, 1976a.
[b]Adapted from Electric Power Research Institute, 1979.
[c]Adapted from Stanford Research Institute, 1976b.
[d]Derived from U.S. Dept. of Agriculture, 1976.
[e]Adapted from Sibbald and Price, 1976.
[f]Calculated from Stanford Research Institute, 1978.

Table 3.2. Crop Residue Cost at Different Stages of Management

Residue	$/Ton as Received					$/Ton Delivered Cost
	Residue Price	Estimated Collection Cost[a]	Total Cost to Purchase at Roadside	Transportation Cost[b]	Total Delivered Cost	
Corn	$11.80-14.80	$4.60-9.90	$16.40-24.70	$2.50-3.00	$18.90-27.70	$35.66-52.26
Soybeans	16.11-18.11	4.60-9.90	20.71-28.01	2.50-3.00	23.21-31.01	27.31-36.48
Oat Straw	12.78-14.78	4.60-9.90	17.38-24.68	2.50-3.00	19.88-27.68	22.09-30.76
Wheat Straw	10.55-12.55	4.60-9.90	15.15-22.45	2.50-3.00	17.65-25.45	19.61-28.28
Corncobs	--	--	12.00	2.50-3.00	14.50-15.00	17.06-17.65

SOURCE: Stanford Research Institute, 1978.
[a]Field collection including cost to roadside corn and soybean and assumes chopping and stacking.
[b]Transportation 15 miles to conversion site.

3.3 QUANTITY OF CROP RESIDUES

The quantity of annual crop residues generated every year in Illinois is perhaps the highest in the nation. Based on the approach described in Section 3.2, it is estimated that the seven main annual crops produced nearly 39.2 million dry tons of residues in 1978. On a per-acre basis, corn residues would average 1.81 tons, soybeans 1.80 tons, wheat 2.60 tons, and oats 2.43 tons. Of the total tonnage, about 33.5 million dry tons (85.5%) were collectible, and close to 23.6 million dry tons (60.2% of the total produced) were wasted residues. These figures exclude hay and forage residues, which are used entirely for feed. Vegetable residues, and residues generated during processing, packing, storage, and other treatments of crop products are also excluded. Table 3.3 shows estimated residues from the main annual crops in Illinois for 1978.

Crop residue generation in Illinois increases every year, due mainly to rising soybean and corn grain production. Table 3.4 tabulates residues generated from 1970 through 1978, as well as the collectible and wasted amounts for the same period. Figure 3.2 indicates crop residue trends for Illinois. Data on estimated crop residues for each Illinois county are listed in Appendix Tables A-1 through A-7. Estimated 1978 residue tonnages for the leading counties, however, are included in Tables 3.5 and 3.6. During 1978, the twenty leading counties in corn, soybean, and wheat residues produced 45.58%, 42.54%, and 61.43%, respectively, of the total residue ton-

Table 3.3. Estimated Generation of Crop Residues in Illinois, 1978 (Thousands of Dry Tons)

Crop	Residues	Collectible Residues	Wasted Residues
Corn	19,442.1	17,498.2	7,873.9
Soybeans	16,558.5	13,239.5	13,252.9
Wheat	2,414.1	2,520.0	2,031.4
Oats	667.4	567.3	425.5
Sorghum	81.3	73.2	29.3
Rye	18.5	15.8	15.6
Barley	13.8	11.7	11.6
TOTAL	39,186.9	33,457.7	23,627.1

Table 3.4. Estimated Production of Residues from the Four Main Annual Crops in Illinois, 1970-1978 (Thousands of Dry Tons)

	CORN			SOYBEANS		
Year	Residues	Collectible	Wasted	Residues	Collectible	Wasted
1970	12,007.3	10,806.6	4,863.0	11,503.4	9,202.7	9,202.7
1971	17,417.7	15,675.9	7,054.2	12,875.8	10,300.6	10,300.6
1972	16,567.8	14,911.0	6,710.0	14,157.6	11,326.1	11,326.1
1973	16,023.5	14,421.1	6,489.5	15,350.2	12,280.2	12,280.2
1974	13,413.4	12,072.1	5,432.4	11,053.7	8,843.0	8,843.0
1975	20,468.7	18,421.8	8,289.8	16,344.8	13,075.8	13,075.8
1976	20,243.9	18,219.5	8,198.8	13,614.1	10,891.3	10,891.3
1977	18,991.3	17,092.2	7,691.5	18,351.9	14,681.5	14,681.5
1978	19,442.4	17,498.2	7,874.2	16,549.4	13,239.5	13,239.5
	WHEAT			OATS		
1970	2,603.3	2,212.8	2,190.7	1,485.3	1,262.5	946.9
1971	3,142.3	2,670.9	2,644.2	1,508.2	1,282.0	961.5
1972	3,688.7	3,135.4	3,104.1	1,201.4	1,021.2	765.9
1973	2,664.1	2,264.5	2,241.8	857.3	728.7	546.5
1974	3,545.3	3,013.5	2,983.4	1,061.0	901.9	676.4
1975	4,608.9	3,917.5	3,878.4	1,080.0	918.0	688.5
1976	4,928.6	4,189.3	4,147.4	971.7	825.9	619.5
1977	4,611.6	3,919.9	3,880.7	898.9	764.0	573.0
1978	2,414.1	2,052.0	2,031.4	667.4	567.3	425.5

nage. Likewise, the ten leading counties in oats, sorghum, and rye residue for 1978 generated 45.1%, 44.4%, and 28.6% of the total residue from these three crops. This means that crop residues are generated in certain areas in considerable amounts, thus justifying their exploitation at both small and large scales.

Crop residues are presently used only as livestock feed, as feedstock for industry, or are plowed under and incorporated in the soil. A great amount of residue is "wasted" by being disposed of, sometimes at cost, or by burning; in several instances, the residue becomes an environmental, health, and safety problem. Basically, the wasted residues are of no direct economic

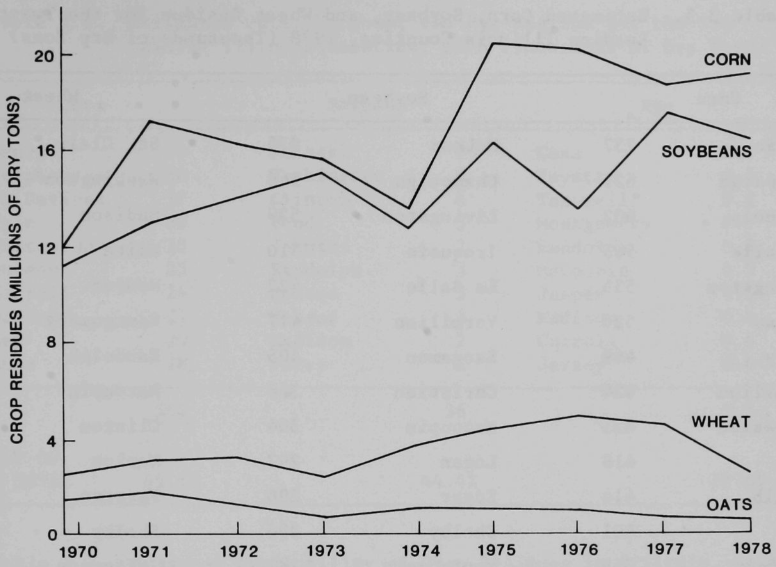


Fig. 3.2. Illinois Crop Residues, 1970-1978

value, except for that which is incorporated into or spread on the soil. It is this kind of residue that should be first considered as a source of energy and fuels. The amount of "wasted" residues is estimated for the state (Table 3.3) and for each county (Appendix Tables A-1 through A-7). Nearly 23.6 million dry tons of wasted residue were generated in 1978, equivalent to 60% of all crop residue produced.

3.4 SEASONAL AVAILABILITY OF RESIDUES

Seasonal availability of biomass material for energy and fuel purposes is critical. Forest residues, for example, are generally available the year around, while annual-crop residues are generated only at certain times of the year. Specifically, Illinois crop residues are generated during the summer (wheat, oats) and fall (corn and soybeans). Table 3.7 shows the tonnage of the state's main crop residues produced in each quarter of 1978, as well as the percentages of the total production of each particular crop residue. The data in Table 3.7 are presented graphically in Figure 3.3, where the seasonal

Table 3.5. Estimated Corn, Soybean, and Wheat Residue for the Twenty Leading Illinois Counties, 1978 (Thousands of Dry Tons)

Corn		Soybean		Wheat	
McLean	737	McLean	575	St. Clair	144
Champaign	621	Champaign	546	Washington	132
Iroquois	602	Livingston	529	Madison	107
La Salle	565	Iroquois	510	White	87
Livingston	555	La Salle	422	Monroe	86
Bureau	525	Vermilion	417	Montgomery	82
Henry	469	Sangamon	405	Randolph	78
Vermilion	424	Christian	358	Macoupin	76
Whiteside	421	Macoupin	304	Clinton	74
Ogle	418	Logan	297	Marion	72
DeKalb	414	Edgar	296	Fayette	65
Lee	401	Shelby	296	Shelby	64
Sangamon	369	Montgomery	281	Jefferson	58
Knox	359	Macon	275	Effingham	56
Tazewell	346	Hancock	272	Bond	55
Warren	335	Ford	265	Hamilton	52
Logan	334	Kankakee	259	Clay	51
Kankakee	333	Douglas	256	Wayne	51
Macon	320	Piatt	239	Jersey	50
Piatt	313	Coles	238	Crawford	43
TOTAL	8,861		7,040		1,483
PERCENT OF STATE TOTAL	45.58%		42.54%		61.43%

accumulation of several million tons of residues is clearly seen. This emphasizes the existing problem of residue storage, which must be solved before attempting to utilize the residue for production of energy and fuel. The storage problem should be given priority consideration for those counties with the highest tonnages of residues.

Table 3.6. Estimated Oats, Sorghum, and Rye Residue for the Ten Leading Illinois Counties, 1978 (Thousands of Dry Tons)

Oats		Sorghum		Rye	
Henry	70	Pulaski	7	Cass	0.8
Stephenson	38	Washington	6	Fayette	0.7
Jo Daviess	37	Clinton	4	Tazewell	0.6
Ogle	30	Bond	3	Montgomery	0.5
Whiteside	28	Johnson	3	Randolph	0.5
Bureau	25	Randolph	3	Macoupin	0.5
Carroll	24	Monroe	3	Jasper	0.5
McHenry	21	Massac	3	Madison	0.4
Lee	20	Madison	2	Carroll	0.4
Knox	18	Perry	2	Jersey	0.4
TOTAL	301		36		5.3
PERCENT OF STATE TOTAL	45.1%		44.4%		28.6%

Table 3.7. Seasonal Availability of Crop Residues in Illinois, 1978 (Thousands of Dry Tons and Percentage of Annual Residues)

June			July			August		
WHEAT RESIDUES (1,000 Dry Tons)								
		483 (20%)	1,086 (45%)	628 (26%)	217 (9%)			
OATS RESIDUES (1,000 Dry Tons)								
			33 (5%)	127 (19%)	227 (34%)	220 (33%)	60 (9%)	
		483	1,119	775	444	220	60	

September			October			November		
CORN RESIDUES (1,000 Dry Tons)								
		2,527 (13%)	3,305 (17%)	5,066 (26%)	4,083 (21%)	2,916 (15%)	972 (5%)	583 (3%)
SOYBEAN RESIDUES (1,000 Dry Tons)								
165 (1%)	662 (4%)	4,468 (27%)	4,965 (30%)	3,144 (19%)	1,986 (12%)	1,158 (7%)		
165	662	6,995	8,270	8,199	6,069	4,074	972	583

NOTE: Percentages have been taken from Illinois Dept. of Agriculture, 1979.

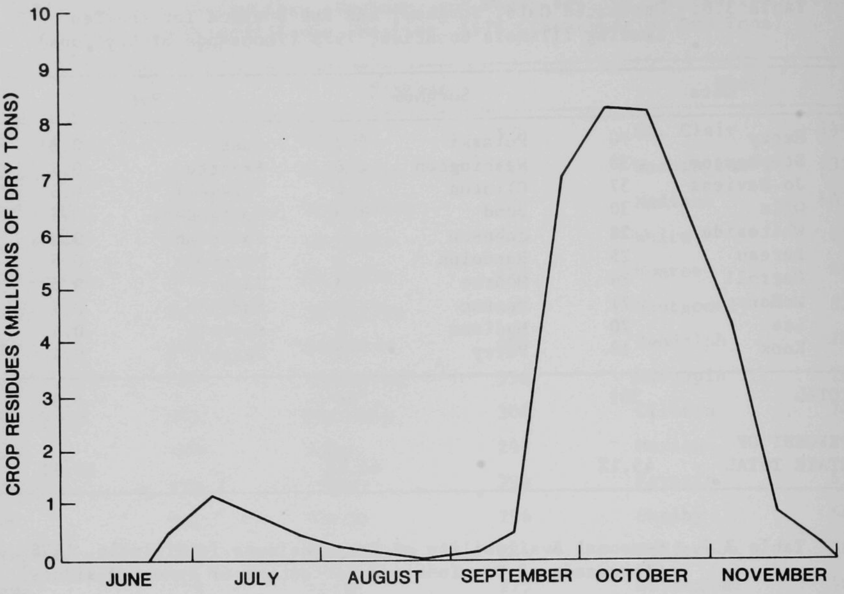


Fig. 3.3. Diagram of Monthly Availability of Residues from Corn, Soybeans, Wheat, and Oats in Illinois, 1978

3.5 COLLECTION, TRANSPORTATION, AND STORAGE

Collection, transportation, and storage of crop residues depend upon the residue type, physicochemical state, seasonal availability, and distance from the field to the conversion site. Other important factors include needed processing time, crop management requirements, availability of harvesting and packing machinery, existing storage facilities, adequacy of the transportation network, availability of workers, and several other factors of local importance.

For Illinois crop residues, most of these determining factors are favorable. The type and physicochemical state of the Illinois crop residues are well suited to harvesting and packing with existing and/or supplemented (modified) machinery. The transportation network is adequate. Distance from the field to expected conversion plants is short and is mostly within desired economic limits, since residue generation is usually local. On the other hand, there are certain problems stemming from the seasonal availability of residues and crop management practices. In Illinois, most residue is generated from corn and soybeans. At harvest, farm workers are busy; residues should be removed immediately after harvesting for crop management reasons (e.g., soil preparation, etc.) and existing machinery is occupied with the harvest. Another potential problem is the matter of adequate storage facilities for the residues. Therefore, it is necessary that these issues be resolved before planning crop-residue utilization. Additional workers, machinery, and storage facilities will reduce or remove these obstacles. Stanford Research Institute investigators (1978) have estimated that for Illinois conditions the costs per fresh-weight ton of crop residues delivered at the roadside are \$6.50-\$16.50 for conventional baling, \$4.60-\$9.90 for chopping and stacking, and \$5.23-\$11.96 for giant round bales (1978 dollars). In addition, the estimated costs for collecting, transporting, and delivering to the conversion site (15 miles from the field) of the four main crop residues in Illinois have been worked out by the same investigators, and are listed in Table 3.2. These costs appear to be reasonable and thus provide the basis for a more thorough study.

3.6 PHYSICAL AND CHEMICAL FEATURES OF CROP RESIDUES

Both physical and chemical characteristics of residues determine their usefulness as a resource material. In the case of bioenergy production, moisture content and the shape and size of residues are the important physical characteristics, in addition to Btu value. The shape and size of Illinois crop residues indicate the need for chopping, packing, or baling. Conventional methods of residue handling seem to be adequate. The moisture content should be reduced to the minimum for transportation, storage, and conversion. Table 3.8 lists the moisture content of crop residues. Solar radiation is the most economic method for drying residues in the field, if it does not conflict with important crop management practices.

Chemical constituents of crop residues are also shown in Table 3.8. The macronutrient content (N, P, and K) of the residues is important for soil fertility. Nitrogen and sulfur constituents are related to pollution effects during conversion of residues to fuels and energy. Moisture and ash contents affect the efficiency of conversion processes of residues. Lignocellulosic percentage is very important in energy and fuel production, since lignin and

Table 3.8. Moisture Content (as Percentage of Fresh Weight) and Chemical Composition (as Percentage of Dry Weight) of Crop Residues

Residue	Moisture Content	Cellulose	Hemi-celluloses	Lignin	Lipids	Protein	Ash	Nitrogen
Corn Husk	--	4.28	4.73	0.87	0.12	0.36	0.44	--
Corn Leaf	47	2.57	2.90	0.60	0.28	0.82	1.60	1.5
Corn Stalk	70	18.54	12.77	5.66	0.92	1.99	2.54	
Corn Cob	--	7.43	7.94	1.58	0.09	0.60	0.30	--
Total Corn Stover	47	32.8-40	28.34	8.71-15.1	1.41	3.77	4.3-4.88	--
Soybean Straw	15	31	--	17.5-20.1	--	5.1-6.0	--	--
Soybean Hulls	--	45.8-52	17.7	3.2	--	13.6	5.1	--
Wheat Straw	10	50	--	8.02-18.0	1.25	2.71	4.3-11.0	0.988-4.5
Oat Straw	10	--	--	7.41	2.0	7.74	10.39	--
Barley Straw	9	52.7	29.2	13.8-15.5	--	--	5.5-10.8	0.5
Rye Straw	28	34.0-36.8	27.2	4.7-5.4	--	--	2.0	--
Sorghum	60	--	--	--	--	--	16.0	--

Adapted from Solar Energy Research Institute, 1979, and supplemented by Stanford Research Institute, 1978, and Electric Power Research Institute, 1979.

cellulose are the main sources of carbon (the necessary element for the formulation of fuels) and are the main releasers of thermal energy after processing. Carbohydrate, protein, and lipid contents of residues are valuable livestock nutrients and industrial substances. Therefore, a thorough knowledge of the main constituents of crop residues at the local level is important for planning and decisionmaking. Generally, crop residues are substantially less polluting during their processing than are coal and feedstocks for fuel and energy generating technologies.

3.7 ENERGY VALUE OF RESIDUES

The energy value of biomass is customarily expressed as a Btu equivalent. The estimated Btu equivalent of cellulose is considered to be 7,500 Btu/lb, and that of lignin as 12,000 Btu/lb (close to that of coal). Some authors have adopted 7,500 Btu/lb (or 15 x 10^6 Btu/ton) (Stanford Research Institute, 1978), while others use 8,400 Btu/lb (= 16.8 x 10^6 Btu/lb) of crop residue thermal equivalent (Electric Power Research Institute, 1979). The latter value has been employed for the energy estimations in this work, since it represents more closely the real thermal value of the residue constituents (lignin, cellulose, hemicelluloses, etc.).

The energy value of Illinois crop residues is shown as a Btu thermal equivalent in Table 3.9. According to this preliminary analysis, the seven main crops yearly supply Illinois with 23.6 million dry tons of waste residues that are suitable for fuel-energy generation. Assuming the thermal equivalent of one bbl of crude oil as 5.8 x 10^6 Btu and the conversion efficiency of residues as 45%, the total energy theoretically available yearly from Illinois crop residues is equivalent to that from more than 51 million bbl of crude oil. Realistically, however, it is likely that the actual energy produced -- from wasted residues only -- would be equivalent to that from about 31 million bbl. Of this, soybean contributes 56%, corn more than 33%, and wheat more than 8%. Oats, sorghum, rye, and barley residues (more than 2%) are primarily of local importance.

In order to determine the estimated energy equivalent (for 1978) from wasted crop residues in Illinois and, therefore, indicate its contribution to the state's energy needs, Table 3.10 lists 1978 Illinois energy production, consumption, and importation. The energy obtained from waste residues could

Table 3.9. Thermal Equivalent Energy of Crop Residues in Illinois, 1978

Crop Residue	Residues: Production (1,000 Dry Tons)	Residues: Energy Value (10^9 Btu)	Residues: Percentage of Total	Wasted Residues: Production (1,000 Dry Tons	Wasted Residues: Energy Value (10^9 Btu)	Wasted Residues: Percentage of Total
Corn	19,422.1	326,627.3	49.60	7,873.9	132,281.5	33.31
Soybean	16,558.5	278,182.8	42.25	13,252.9	222,648.7	56.06
Wheat	2,414.1	40,556.9	6.15	2,031.4	34,127.5	8.59
Oats	667.4	11,212.3	1.70	425.5	7,148.4	1.80
Sorghum	81.3	1,365.8	0.21	29.3	492.2	0.12
Rye	18.5	310.8	0.05	15.6	262.1	0.07
Barley	13.8	231.8	0.04	11.6	194.9	0.05
TOTAL	39,195.7	658,487.7	100.00	23,640.2	397,155.3	100.00

replace 17.7% of the oil imported from foreign countries, processed in Illinois, and partially consumed within the state. Alternatively, the 178.2 x 10^{12} Btu (34% of 397.16 x 10^{12} Btu) of wasted residues could easily cover 73% of electrical power needs or 15% of natural gas requirements. It should be emphasized that the estimated amount of energy is a product of only a part of the available biomass in Illinois; the total amount will increase substantially in the coming years through application of better biomass-production practices, and the usable energy of biomass will also increase through new developments in conversion technologies. Basically, a comprehensive study of the total Illinois biomass potential is needed.

3.8 ECONOMICS OF RESIDUES

Table 3.11 shows the estimated cost of a dry ton of crop residues that is to be delivered to a conversion plant 15 mi (average) from the field. The table also shows energy cost per million Btu. Corn residue is the most expensive, while that of wheat is less costly.

In many cases, crop residues are disposed of by returning them to the soil, a procedure that is known to be beneficial. Stanford Research Institute investigators have calculated the beneficial value of crop residues returned to the soil, and this value is also included in Table 3.11. Soybean

Table 3.10. Energy Production, Consumption, and Importation in Illinois, 1978

	Quantity	Thermal Value (10^{12} Btu)
PRODUCTION[a]		
Natural Gas	$1,159 \times 10^6$ ft^3	1.27
Crude Oil	$23,362 \times 10^3$ bbl	135.50
Coal	$21,767 \times 10^3$ tons	57.03
Nuclear	$32,926 \times 10^6$ kWh	112.38
Electricity[b]	$71,696 \times 10^6$ kWh	244.70
CONSUMPTION		
Natural Gas	$1,161,536 \times 10^6$ ft^3	1,185.93
Crude Oil	$324,850 \times 10^3$ bbl	1,884.13
Coal	$38,299 \times 10^3$ tons	100.34
Nuclear	$32,926 \times 10^6$ kWh	112.38
Electricity[b]	$71,696 \times 10^6$ kWh	244.70
IMPORTATION[a]		
Natural Gas	$1,208,157 \times 10^6$ ft^3	1,233.53
Crude Oil[c]	$421,001 \times 10^3$ bbl	2,441.81
Coal	$16,934 \times 10^3$ tons	44.38

SOURCES: U.S. Dept. of Energy, 1978; National Coal Association, 1978 and 1979.

[a]Produced and imported fuels for both intrastate consumption and interstate exportation.

[b]Electricity includes nuclear energy and part of oil ($12,899 \times 10^3$ bbl), gas ($22,568 \times 10^6$ ft^3), and coal ($33,423 \times 10^3$ tons) energy.

[c]Imported oil: $246,960 \times 10^3$ bbl interstate, and $174,041 \times 10^3$ bbl foreign.

Table 3.11. Estimated Delivered Cost of Convertible Residues[a] and Beneficial Value of Disposed Residues[b] in Illinois, 1978

Residue	Delivered Cost ($/Dry Ton)	Energy Cost ($/$10^6$ Btu)	Value of Disposed Residues ($/Ton as is)
Corn	36.66 - 52.26	2.18 - 3.11	11.80 - 14.80 (to soil, livestock)
Soybean	27.31 - 36.48	1.63 - 2.17	16.11 - 18.11 (to soil)
Wheat	19.61 - 28.28	1.17 - 1.68	10.55 - 12.55 (to soil)
Oats	22.09 - 30.76	1.31 - 1.83	12.78 - 14.78 (to soil)

Adapted from Stanford Research Institute, 1978.

[a]Residues transported from a field 15 mi from the conversion site.

[b]Possible beneficial value of residues by disposing of them in soil or by feeding livestock (20% of corn, only).

Table 3.12. Estimated Nutrient Content and Value of Main Crop Residues in Illinois, 1978

Residue	N[a]		P_2O_5[a]		K_2O[a]		Other[b] Value ($)	Total Value ($)
	lb/Ton	$/Ton	lb/Ton	$/Ton	lb/Ton	$/Ton		
Corn	20	2.40	6	1.02	17	1.36	7.00-10.00	11.78-14.78
Soybean	47	5.64	11	1.87	20	1.60	7.00- 9.00	16.11-18.11
Wheat	12	1.44	3	0.51	20	1.60	7.00- 9.00	10.55-12.55
Oats	13	1.56	6	1.02	40	3.20	7.00- 9.00	12.78-14.78

Adapted from Stanford Research Institute, 1978.

[a]Assumed prices \$0.12/lb N, \$0.17/lb of P_2O_5, and \$0.08/lb of K_2O fertilizers.

[b]Includes value of residues in adding soil organic matter, controlling erosion, and conserving soil moisture.

residues returned to soil appear to offer the highest benefit, due mainly to their nitrogen content. Computation of the beneficial value is based on the estimated nutrient (N, P_2O_5, and K_2O) content of the crops, as is shown in Table 3.12.

The delivered cost of crop residues depends, among other factors, on the production cost, type of collection and packing, and transportation distance. Table 3.13 lists the estimated delivered cost for cereal straw packed as bales or stacks and transported from different distances. It appears that stacking is slightly less expensive than baling.

Dr. W. A. Stout of Michigan State University, in a personal communication with Purdue University staff members, estimated the production cost of corn and wheat in Indiana (Table 3.14). The total cost per acre for corn is \$263, and for wheat \$181. Land accounts for 35% of the total cost for corn, and 51% for wheat. Machinery and equipment account for 16% of the total for corn, and 10% for wheat.

The extensive use of farm machinery significantly increases consumption of fossil fuels, of which supplies are decreasing and prices are increasing. Thus, the energetics of crop production are closely tied to the cost of residue generation. Table 3.15 is included in this study to show the estimated average energy inputs and outputs for five major annual crops in the United States. The data are based on the work of Pimentel and Pimentel (1979). Sorghum production requires more fossil energy than other crops, although corn is the most energy-intensive crop, with both the highest energy output and input. The highest output/input ratio (4.21:1) is obtained for soybeans, followed by oats (3.11:1), corn (2.93:1), wheat (2.41:1), and sorghum (1.96:1). The greatest amount of fertilizer is used for corn, the lowest for soybeans. Actual energy yield (output) for corn is about three times that of soybeans, wheat, or oats, and nearly twice that of sorghum.

Actual energetics data for the Illinois crop residues are not available, and relevant studies should be initiated.

Table 3.13. Estimated Delivery Cost of Cereal Straw as Bales or Stacks from Different Distances ($/Ton)

Distance (mi)	Straw Cost		Collection Cost		Transport Cost		Total Cost	
	Baled	Stacked	Baled	Stacked	Baled	Stacked	Baled	Stacked
10	10	10	21.0	18.6	4.7	6.4	35.7	35.0
20	10	10	21.0	18.6	7.9	9.5	38.9	38.1
30	10	10	21.0	18.6	11.0	12.5	42.0	41.1
40	10	10	21.0	18.6	14.2	15.5	45.2	44.1

SOURCE: Eckhoff et al., 1977.

Table 3.14. Estimated Production Cost of Corn and Wheat per Acre in Indiana, 1979 ($)

Production Cost	Corn[a]	Wheat[b]
Direct Cost Per Acre		
Fertilizer (including lime)[c]	32.00	22.50
Seed and Chemicals	20.00	10.00
Machine Operation and Drying	25.50	11.25
Interest on Operating Capital	9.00	7.00
TOTAL DIRECT COST	86.50	50.75
Indirect Cost Per Acre		
Machinery and Equipment	43.00	18.00
Labor and Management	31.00	20.00
Grain Storage (bin only)	11.00	--
Land Cost[d]	92.00	92.00
TOTAL INDIRECT COST	177.00	130.00
TOTAL COST PER ACRE	263.50	180.75
COST PER BUSHEL	2.40	3.62

Adapted from Stout, 1979.

[a]At 110 bu/acre.

[b]At 50 bu/acre.

[c]Assumed prices: N, $0.12/lb for corn, and $0.20/lb for wheat; P_2O_5, $0.18/lb; K_2O, $0.09/lb. Also assumed is a corn-soybean rotation, and no insecticide application.

[d]Land costs are approximate current cash rental rates.

Table 3.15. Estimated Energy Inputs and Outputs per Acre for Five Major Annual Crops in the United States

	Corn		Soybeans		Wheat		Oats		Sorghum	
Inputs, Outputs	Quan.	10^6 Btu	Quan.	10^6 Btu	Quan.	10^6 Btu	Quan.	10^6 Btu	Quan.	10^6 Btu
INPUTS										
Labor	5 h	0.009	4 h	0.007	3 h	0.005	2.5 h	0.004	5 h	0.009
Machinery	28 lb	0.87	18 lb	0.56	17.8 lb	0.58	17.8 lb	0.58	27.7 lb	0.90
Diesel Fuel	12 gal	2.05	0.7 gal	0.13	5.7 gal	0.97	4.8 gal	0.82	14.5 gal	2.47
Gasoline	--	--	0.5 gal	0.06	--	--	--	--	--	--
Nitrogen	117 lb	3.02	3.6 lb	0.08	46.6 lb	1.15	13.4 lb	0.35	69.6 lb	1.84
Phosphorus	61 lb	0.35	16 lb	0.09	23.2 lb	0.13	10.7 lb	0.06	27.7 lb	0.15
Potassium	71 lb	0.21	42 lb	0.12	26.8 lb	0.08	18.7 lb	0.06	8.9 lb	0.02
Limestone	89 lb	0.05	312 lb	0.18	31.2 lb	0.02	26.8 lb	0.02	26.8 lb	0.01
Seed	19 lb	0.84	54 lb	0.77	94.6 lb	1.12	83 lb	1.16	26.8 lb	0.67
Irrigation	--	1.25	--	--	--	--	--	--	--	1.00
Insecticides	0.9 lb	0.14	--	--	--	--	--	--	0.9 lb	0.14
Herbicides	1.8 lb	0.32	5 lb	0.80	0.4 lb	0.08	0.2 lb	0.03	4.0 lb	0.72
Drying	--	0.68	--	--	--	--	--	--	--	--
Electricity	--	0.61	--	0.05	--	0.32	--	0.32	--	0.61
Transportation	121 lb	0.06	89 lb	0.04	104.9 lb	0.07	141 lb	0.07	144.6 lb	0.07
TOTAL		10.45		2.89		4.52		3.47		8.6
OUTPUTS										
Yield	86 bu	30.75	28 bu	12.18	30.5 bu	10.92	48 bu	10.79	48 bu	16.94
Btu output/ input ratio		2.93		4.21		2.41		3.11		1.96

Based on Pimentel and Pimentel, 1979.

4 CANNING AND FOOD PROCESSING WASTES

4.1 INTRODUCTION

Canning of food is done by heating the food to boiling and then packing and sealing it in sterilized anaerobic containers. In canning, certain desirable natural qualities of fresh food are lost. The sterile anaerobic conditions in a container keep the food free of microbial activities and preserve it for long periods. In freezing, the low temperatures (-18°C) inhibit any microbial action. Steaming of vegetables for a short time before freezing inactivates the enzymes that damage the natural flavors and colors. Drying, another way of preserving foods, minimizes the moisture content (below 12%) and thus prevents microbial actions that destroy or poison foods.

In the United States, according to the 1972 Census of Manufacturers, the food industry includes nearly 30,000 manufacturing establishments and employs more than 1.7 million workers. The industry processes canned and preserved fruits and vegetables, dairy products, grain mill products, meat products, bakery products, sugar and confectionery products, fats and oils, beverages, and many other items. In particular, canned and preserved fruits and vegetables include canned specialties, fruits, vegetables, preserves, jams and jellies; dried and dehydrated fruits, vegetables, and soup mixes; pickled fruits and vegetables, vegetable sauces and seasonings, and salad dressings; frozen fruits, fruit juices and vegetables; and frozen specialties.

The U.S. food industry generates an enormous amount of wastes each year. It has been estimated that, in 1973, processed corn for food generated 1.6 million dry tons of residues, mostly in the north-central states (U.S. Environmental Protection Agency, 1973). Processed white potatoes generated nearly 1.2 million dry tons of residuals, mostly in the Northwest. General calculations have shown that by converting all food processing wastes in the U.S. to alcohol, nearly 800 millions gal could be produced (close to 0.8% of current annual U.S. gasoline consumption) (Guymont and Alpert, 1978). This justifies a thorough investigation of the canning and food processing wastes as an energy-fuel source.

In this preliminary analysis the wastes generated by the principal Illinois vegetable, fruit, and milk processing industries will be studied.

While a lack of certain information on particular elements of this work has been a problem, this did not hinder the development of conclusions about the potential of Illinois canning and food processing wastes as sources of energy and chemicals.

4.2 ASSESSMENT APPROACH

The quantification of annually generated wastes from Illinois canning and food processing industries was based on available statistical information on produced feedstock for the industries; appropriate conversion factors were employed. Illinois Dept. of Agriculture (1979) lists the amount of vegetables processed, as well as the amount of milk and cheese produced, for 1978. The Illinois Department of Commerce and Community Affairs provides data for the food products industries of the state. The U.S. Bureau of the Census furnished, through the 1972 Census of Manufactures, statistical data for Illinois.

Principal processed vegetables in Illinois are sweet corn, snap beans, cabbage for sauerkraut, cucumbers for pickles, lima beans, green peas, tomatoes, asparagus, and carrots. Estimated percentages of total solid waste utilized as by-product and handled as solid waste are shown in Table 4.1. These percentages have been employed to estimate the generation of solid wastes from the Illinois food processing industries that use only vegetables produced in the state.

Table 4.1. Estimated Percentages of Illinois Food-Processing Solid Wastes

Vegetable Processed	Total Waste Produced (%)	Utilized as By-Product (%)	Handled as Solid Waste (%)
Beans, Green	21	10	11
Beets	41	21	20
Carrots	41	21	20
Corn	66	62	4
Tomatoes	8	2	6
Vegetables (misc.)	22	9	13

SOURCE: U.S. Environmental Protection Agency, 1973.

Another food industry by-product that is a potential source of fuel is whey, the watery part of milk separated during preparation of cheese. Illinois Dept. of Agriculture (1979) lists the milk produced by county (see Table A-8 in the appendix) and the total production of dairy products. During cheesemaking, approximately 9 lb of sweet whey are produced per lb of cheese, and nearly 5.2 lb of acid whey are generated per lb of cottage cheese (Sommer, 1979). Both sweet and acid wheys contain, on an average, 93% moisture (Whey Products Institute, 1975). The above ratios of whey to cheese and whey moisture content have been adapted for this analysis.

4.3 ILLINOIS FOOD PROCESSING AND ASSOCIATED WASTES

The manufacturing and processing of foods in Illinois (identified in the Standard Industrial Classification Manual -- U.S. Office of Management and Budget (1972), as major group SIC 20 - Food and Kindred Products) was conducted by more than 380 establishments in 1979, while in 1973 it was conducted by more than 1300 establishments (Illinois Dept. of Commerce and Community Affairs, 1976, 1979). Illinois is considered as a leader in food manufacturing in the United States, ranking second (in 1973) only to California in value added by manufacture. The state's high volume of agricultural products, existing labor force, industrial heritage, excellent transportation, and appropriate market have kept Illinois as a food manufacturing leader. In 1973, more than 113,000 employees (7.4% of the U.S. total) had a job in Illinois food manufactures, with an average hourly wage of $4.48 per worker (16% higher than the U.S. average). In the same year, the Illinois manufacturing value added was more than $3 billion, or 8% of the nation's total, and the value per production employee was $38,954 (about $2,000 more than the national average). Figures 4.1 and 4.2 show by county the number and size of establishments that process canned and preserved fruits and vegetables (SIC 203) and dairy products (SIC 202) in 1979.

Canned and preserved fruits and vegetables processing is located primarily in Cook County (Chicago area). In 1973, Illinois had 124 such establishments employing over 12,000 workers. In 1979, with only 34 plants and some 8,000 workers, the state's canned and preserved fruits and vegetables firms were substantially reduced in number but total production has increased.

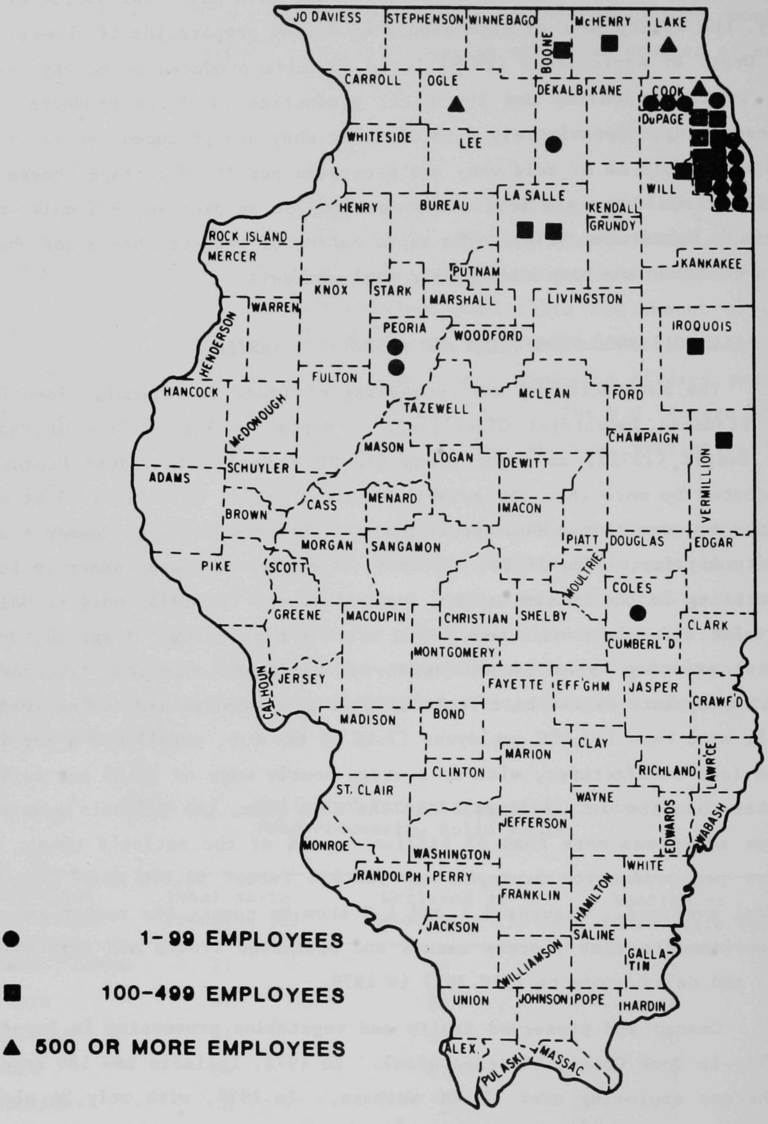


Fig. 4.1. Fruit and Vegetable Processing Establishments (SIC 203) in Illinois, 1979 (Source: Illinois Dept. of Commerce and Community Affairs, 1979)

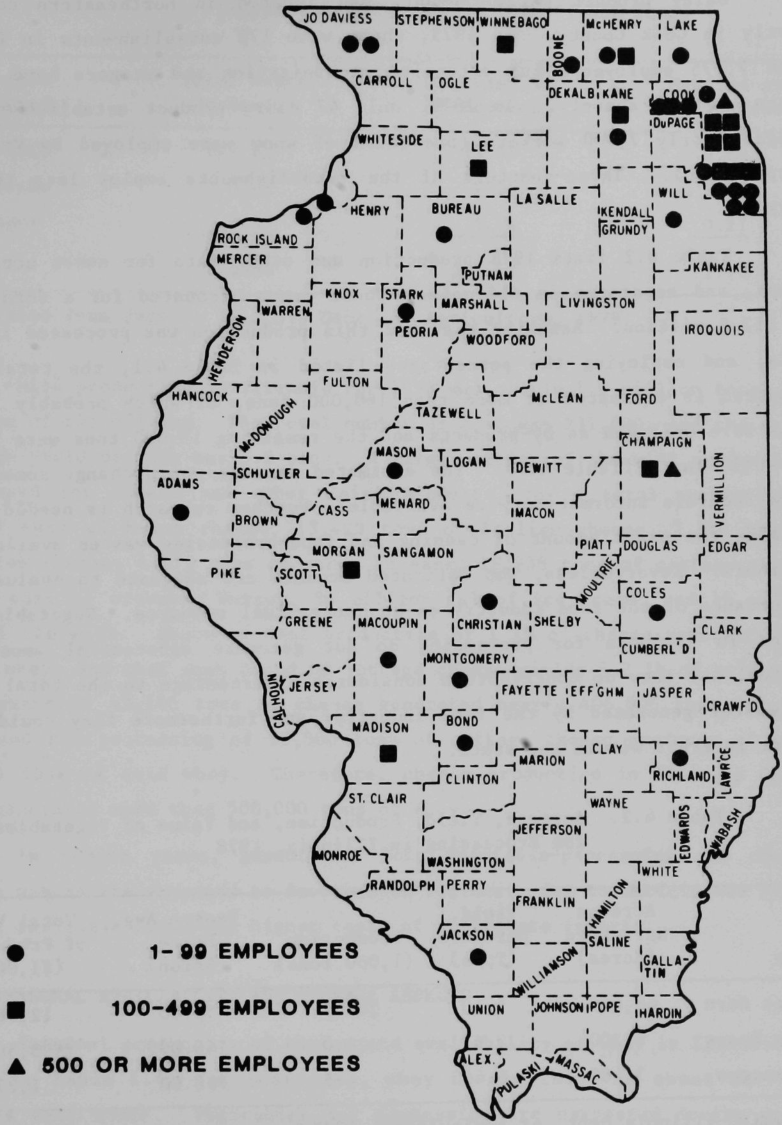


Fig. 4.2. Dairy Product Establishments (SIC 202) in Illinois, 1979 (Source: Illinois Dept. of Commerce and Community Affairs, 1979)

Dairy product establishments are located in northeastern counties, mostly in Cook County. In 1973, there were 178 establishments in Illinois with 7,775 employees, but extensive mechanization and mergers have reduced these numbers sharply. In 1979, only 47 dairy product establishments employed nearly 7,000 workers (one-third of whom were employed by Kraft Co. Corporation). Three-quarters of the establishments employ less than 100 workers.

Table 4.2 lists 1978 production and other data for sweet corn, snap beans, and asparagus in Illinois. These crops accounted for a total value of $17.8 million. Assuming that all this production was processed in Illinois, and employing the percentages listed in Table 4.1, the total waste produced is estimated at more than 168,000 tons, of which probably 155,600 tons were utilized as by-products and the remaining 13,000 tons were handled as solid waste (Table 4.3). The estimated amounts would change somewhat if more accurate information were available. Further research is needed to determine the exact amount of canning and food-processing wastes available in Illinois. Nevertheless, the estimated amounts are adequate to evaluate the importance of the food industry as an energy-fuel resource. Vegetables produced in Illinois for processing do not generate substantial amounts of wastes, but they do contribute a considerable percentage to the total amount of wastes generated by the food industry, and furthermore they could be of local interest within the state.

Table 4.2. Acreage, Yield, Production, and Value of Vegetables for Processing in Illinois, 1978

Crop	Acreage Harvested (Acres)	Yield per Acre (Tons)	Production (1,000 Tons)	Season Avg. Price ($/Ton)	Total Value of Production ($1,000)
Sweet Corn	48,400	5.10	246.9	51.00	12,589
Snap Beans	9,200	2.61	24.0	146.00	3,504
Asparagus	3,480	0.46	1.6	798.00	1,277

SOURCE: Illinois Dept. of Agriculture, 1979.

Table 4.3. Estimated Waste from Vegetable Processing Industries in Illinois, 1978 (1,000 Tons)

Vegetable Processed	Total Waste Produced	Utilized as By-Product	Handled as Solid Waste
Sweet Corn	162.95	153.08	9.88
Snap Beans	5.04	2.40	2.64
Asparagus	0.35	0.14	0.21
TOTAL	168.34	155.62	12.73

Calculated from data in Illinois Dept. of Agriculture, 1979.

Milk production in Illinois for 1978 was nearly 1.2 million tons, with a value of $25 million. The total number of cows was 231,000, and the annual average yield per cow was 5.2 tons. A large portion of the milk produced was processed for cheese and other dairy products, for a total production of 23,865 tons of Swiss cheese, 13,420 tons of Italian cheese, 3,344 tons of American cheese, 4,477 tons of other cheeses, 18,758 tons of cottage cheese, 1,854 tons of creamery butter, 34 million gal of ice cream, and 16 million gal of ice milk. Assuming that production of 1 lb of cheese generated 9 lb sweet whey, and that each pound of cottage cheese yields 5.2 lb of acid whey, the making of 45,106 tons of cheese generated nearly 406,000 tons of sweet whey and the processing of 18,800 tons of cottage cheese produces close to 97,500 tons of acid whey. Therefore, cheese production in Illinois during 1978 generated more than 500,000 tons of whey.

In coming years, amounts of both vegetable-processing and cheese-making wastes are expected to increase in Illinois, due to anticipated higher demand for these foods and higher costs of interstate imports.

4.4 SEASONAL AVAILABILITY AND STORAGE ASPECTS

Seasonal production of cheese and availability of whey in Illinois are shown in Table 4.4. As indicated, whey is available in about the same amounts each month. Vegetables for processing are harvested during summer and fall, but because the processing extends beyond those periods, storage facilities are required. Availability of processing wastes is thus spread over a longer period than that for corn, soybeans, and related crops.

Table 4.4. Seasonal Production of Cheese[a] and Availability of Whey[b] in Illinois, 1978 (10^3 tons)

Cheese Type	J	F	M	A	M	J	J	A	S	O	N	D
Swiss	1.96	1.95	2.13	2.01	2.33	2.47	2.22	2.13	1.74	1.44	1.63	1.86
Italian	0.99	0.91	1.10	0.98	1.12	1.08	1.01	1.14	1.07	1.67	1.16	1.21
American	0.19	0.20	0.34	0.26	0.21	0.23	0.28	0.37	0.34	0.26	0.34	0.30
Cottage	1.49	1.58	1.77	1.72	1.78	1.67	1.68	1.78	1.67	1.35	1.19	1.08
Other	0.35	0.33	0.37	0.34	0.40	0.44	0.40	0.42	0.37	0.39	0.32	0.35
Whey	39.16	38.73	44.66	41.25	45.80	46.66	43.93	45.80	40.36	40.86	37.67	39.10

[a]Calculated from data in Illinois Dept. of Agriculture, 1979.

[b]Estimates based on the assumption that in processing 1 lb of cheese, 9 lb of whey are generated, and in processing 1 lb of cottage cheese, 5.2 lb of whey are generated.

4.5 PHYSICAL AND CHEMICAL CHARACTERISTICS OF WASTES

Solid wastes from processed vegetables are produced by the trimming of inedible, damaged, decayed, and otherwise undesirable parts. In particular, corn wastes are the husks, silk, cobs, ends of ears, overmature ears, and damaged ears. Bean wastes consist of the pod ends, damaged pods, and overmature pods. Mostly, these solid wastes are used to feed livestock and make other products. Nearly two-thirds of corn for processing becomes solid waste which, in most cases, is sold as silage ($10 to $50 per day ton after chopping and stacking). The high water content makes this material less transportable and creates a problem of storage. Some canning industries upgrade corn silage to make it more consumable for livestock.

Liquid wastes are produced in enormous amounts due to the use of large quantities of water during vegetable processing and to the high water content of the vegetables. Such liquid wastes contain appreciable amounts of dissolved and suspended organic material, much of which is recycled at the plant. Table 4.5 lists the estimated amount of wastewater released, biochemical oxygen demand (BOD), and suspended solids per ton of processed vegetables. Due to pollution effects of the liquid wastes, the industry is open to recommendations on ways to convert the wastes to useful products.

Table 4.5. Components of Wastewater from Canned and Frozen Vegetables

Vegetable Processed	Wastewater (10^3 Gal/Ton)	BOD (lb/Ton)	Suspended Solids (lb/Ton)
Corn	1.8	25	10
Snap Beans	4.5	30	4
Asparagus	10.0	10	7
Carrots	4.0	55	40
Tomatoes	2.0	12	4
Other Vegetables	4.0	60	30

SOURCE: U.S. Environmental Protection Agency, 1973.

Table 4.6. Percentage Composition of Wheys

Components	Sweet Whey	Acid Whey
Water	93.0	93.0
Lactose	4.9	4.7
Protein	0.9	0.9
Ash	0.6	0.7
Non-protein N and Fat	0.6	0.7

SOURCE: Whey Products Institute, 1975.

The most important of all liquid food-processing wastes is whey, derived from cheese production. The composition of liquid wheys is shown in Table 4.6. Whey is mostly water (about 93%), but its lactose content is at exploitable levels. A considerable amount of whey (about 40%, national average) is utilized in foods (candies, infant foods, etc.) and feeds. The rest is largely wasted or disposed of. According to Loehr (1974), the number of cheese-manufacturing establishments will decrease by 50% between 1960 and 1980, while cheese consumption will increase. This is due to consolidation of establishments, which means waste generation becomes more concentrated and more managable. Whey has been utilized, at small scales, for single-cell-protein and ethanol production, but no information on production costs is available.

Waste whey in the wash and pasteurization wastewater produces a BOD in the range of 32 to 60 x 10^3 mg/lb (Loehr, 1974).

4.6 ENERGY VALUE OF SELECTED FOOD-PROCESSING WASTES

Assuming that 60% of the lactose contained in the 500,000 tons of whey produced in Illinois in 1978 was available for fermentation, and that about 40% of the lactose was converted (efficiency of conversion depends on several parameters), then more than 1.8 million gal of ethanol could be produced (500 x 10^6 x 4.9 or 4.7 x 0.60 = 14,700 tons of lactose; 14,700 x 2,000 = 29.4 x 10^6 lb lactose; 29.4 x 10^6 x 0.40 = 11.76 x 10^6; 11.76 x 10^6: 6.45 (lb of ethanol/gal) = 1.823,256 gal). This amount of ethanol mixed in a ratio of 1:9 with gasoline could theoretically generate more than 18 million gal of gasohol.

Based on the assumption that one bushel of food-processing wastes (weighing, on the average, 60 lb) can be converted to 2.7 gallons of ethanol (National Petroleum Council, 1978), then the 13 x 10^3 tons of non-utilized waste possibly generated in 1978 during vegetable processing could produce nearly 1.2 million gal of ethanol for Illinois consumers in that year. Making a more optimistic assumption, if all the vegetable-processing waste (168 x 10^3 tons) was fermented to ethanol, then as much as 15 million gal of ethanol, or 150 million gal of gasohol, could supplement the state's fuel needs.

It should be emphasized at this point that wastes generated from vegetables in Illinois constitute a portion of the total tonnage produced annually from general food processing. Furthermore, the estimated wastes represent those generated from processed vegetables that have been grown in Illinois, and not those from vegetables grown elsewhere and imported. The same holds true for whey production, which is not the only waste of dairy processing. This preliminary analysis addresses the importance of a few examples of canning and food-processing wastes as sources of energy, fuels and chemicals in Illinois.

5 CONVERSION TECHNOLOGIES

5.1 INTRODUCTION

Technologies for the conversion of biomass to energy and fuels are characterized as either thermochemical or biological, depending on the means of conversion employed (Fig. 5.1). Recently, a considerable research and development effort has focused on maximizing the effectiveness of these conversion technologies. This preliminary study addresses the use of three specific technologies for converting Illinois biomass to fuels and chemicals, namely direct combustion of crop residues to generate heat and electricity; fermentation of certain crop products, residues, and food-processing wastes to produce ethanol for gasohol; and gasification of certain crop residues to yield methane and chemicals.

From a national, economic, and environmental point of view, biomass conversion to energy and fuels offers several advantages over the processing of fossil-fuel feedstocks. On the other hand, crop residues and food-processing wastes impose certain constraints in utilizing these technologies,

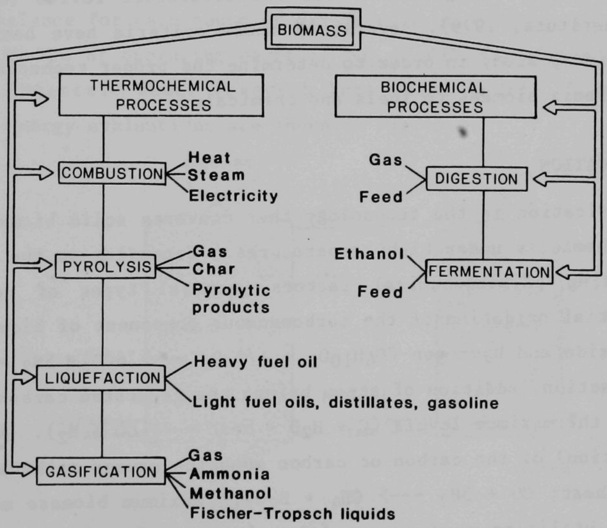


Fig. 5.1. Biomass Conversion Pathways, Technologies, and Principal Products

mainly due to high moisture content, seasonal availability, changes during storage, chemical composition (bound nitrogen, inorganics, etc.), size, shape, and other characteristics. In most cases, special preparation of such biomass feedstock is needed; this requires additional energy, capital, and time. Solar energy can be used to dry most of the crop residues if weather conditions, agronomic limitations, and other related factors permit. Densification and packing will reduce feedstock volume to manageable levels.

Certain criteria have been employed to determine the suitable technology for a particular feedstock. The Electric Power Research Institute (1979) based its selection of technologies for producing liquid fuels from biomass on the availability of technology, successful demonstration with a biomass feedstock, suitability of products for further processing to acceptable fuels, size of conversion plants, and availability of information on heat and material balances to assess fuel yields and efficiency. Furthermore, the authors considered the nature of feedstock, pretreatment required, additional reactants needed, fuel products yield, energy contents, reactor type used, operating conditions, and development status of the technology. Besides such information gathered from the literature review (Electric Power Research Institute, 1979), several of these criteria have been employed in this preliminary study in order to determine the proper technologies for converting Illinois biomass to fuels and chemicals.

5.2 GASIFICATION

Gasification is the technology that converts solid biomass to gaseous fuels and chemicals under high temperatures. Depending on the reactants and the prevailing physicochemical factors, several types of reactions take place. Partial oxidation of the carbonaceous component of biomass generates carbon monoxide and hydrogen ($C_6H_{10}O_5 + 1/2\ O_2 \longrightarrow 6CO + 5H_2 + \text{heat}$). During this reaction, addition of steam brings the generated carbon monoxide and hydrogen to the maximum levels ($C + H_2O + \text{heat} \longrightarrow CO + H_2$). Reduction (hydrogasification) of the carbon or carbon monoxide causes methanation ($C + 2H_2 \longrightarrow CH_4 + \text{heat}$; $CO + 3H_2 \longrightarrow CH_4 + H_2O$). Maximum biomass methanation is obtained by utilizing pure oxygen (the nitrogen of air lowers methanation) during partial oxidation, hydrogasification, and high temperatures and pressures. The produced syngas ($CO + H_2$) is accompanied by CO_2, H_2S, and other compounds that must be removed before processing the syngas. Based mainly on type of reactor, heat transfer system, and main products yielded, several types of gasification processes have been developed (Jones et al., 1978), and a few have been utilized to gasify biomass. Two of the more promising gasifiers, the Moore-Canada, and the Purox, are described below.

The Moore-Canada Company (of Richmond, British Columbia) gasifier is commercially available in reactors that process 60 dry tons of biomass (wood chips) per day. This reactor produces 40,000 scf* of low-Btu gas from each ton of untreated and relatively dry biomass. The reactor uses a vertically-moving packed bed and is operated at 2200°F and 3 to 7 psi. Air is used as the oxidant, and the presence of atmospheric nitrogen lowers the heating value of the raw gas to 180 Btu/scf. However, the use of air permits the oxidation section of the gasifier to work at its maximum temperature of 2200°F. By injecting steam, the hydrogen content of syngas is doubled. The hogged biomass feed enters at the top of the reactor, while air, steam, and tar (from the gas scrubber) enter at the bottom. Waste is mostly discharged in granular form (ash). Figure 5.2 is a schematic of the Moore-Canada gasifier, while Table 5.1 indicates net material balances for this system. The net energy balance for each pound of dry feed is as follows: in, 9,000 Btu of biomass + 238 Btu of operating energy; out, 7,070 Btu of gas + oil for internal use (Electric Power Research Institute, 1979). The energy flow streams and energy evaluations are shown in Fig. 5.3.

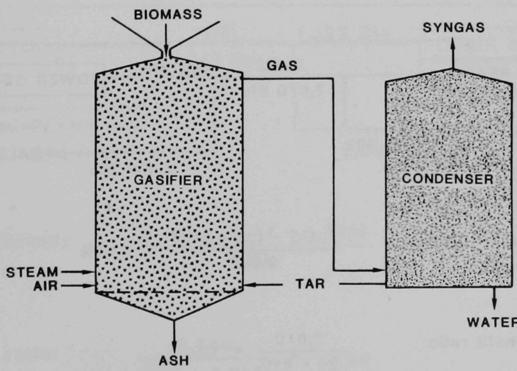


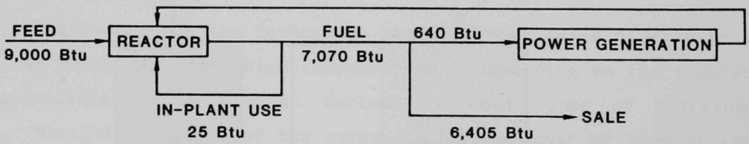
Fig. 5.2 Moore-Canada Gasifier: Main Components, Products, and By-Products (Adapted from Electric Power Research Institute, 1979)

*scf = standard cubic feet

Table 5.1. Net Material Balances for Moore-Canada Gasifier (lb/hr)

Input		Output	
Wood		Raw Gas	
Carbon	63,500	Hydrogen	5,324
Oxygen	7,880	Carbon Monoxide	98,100
Hydrogen	49,740	Carbon Dioxide	54,430
Nitrogen	130	Methane	5,810
Ash	3,750	Hydrocarbons	5,370
Water	125,000	Nitrogen	154,700
Air		Oxygen	2,206
Oxygen	46,875	Water	7,885
Nitrogen	154,570	Ash	3,750
Water	3,455	Condensate	
Steam		Organics	3,600
Water	20,800	Water	134,525
Total Input	475,700	Total Output	475,700

Adapted from Rowell and Hokanson, 1979.

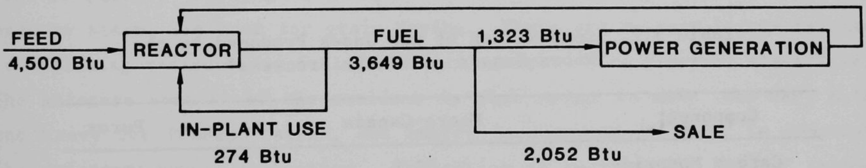


Net thermal efficiency: $\frac{7,070 - (25 + 640)}{9,000} = 71.2\%$

Energy benefit ratio: $\frac{7,070}{25 + 640} = 10.6$

Fig. 5.3. Energy Flow Streams and Energy Evaluations for Moore-Canada Gasifier (Adapted from Electric Power Research Institute, 1979)

Another promising gasification system is Purox, developed by Union Carbide for the processing of municipal solid waste (MSW). The Purox process produces 20,000 scf/ton, using pure oxygen for the partial oxidation of carbonaceous feedstock components. A moving bed is used, and the gasifier operates at 3000°F and zero psi (Anderson, 1973). The produced gas has a thermal value of nearly 300 Btu/scf, which is equivalent to 7.5 x 10^6 Btu/ton of dry feedstock and is 65 to 75% of the dry weight of feedstock input. In the reactor, the material undergoes drying, reduction, oxidation; the raw gas, which is high in moisture and heated to about 200°F, leaves the reactor from the top, while the ash, in molten form and superhot (3000°F), is removed from the bottom. Purox gasification produces a syngas that is high in water and hydrogen sulfide content; the relatively high cost of their removal is offset because the low nitrogen content in the gas (due to use of oxygen rather than air in the conversion process) reduces the cost of compression. The net energy balance per dry pound of feedstock is as follows: in: MSW (biomass) 4500 Btu + operating energy 1323 Btu; out: gas 3649 Btu + Btu from char and oil for internal use (Electric Power Research Institute, 1979). The energy flow streams and energy evaluations are illustrated in Figure 5.4.



Net thermal efficiency: $\dfrac{3{,}649 - (274 + 1{,}323)}{4{,}500} = 45.6\%$

Energy benefit ratio: $\dfrac{3{,}649}{274 + 1{,}323} = 2.28$

Fig. 5.4. Energy Flow Streams and Energy Evaluation for Purox Gasifier (Adapated from Electric Power Research Institute, 1979)

Gas leaving any gasifier must be purified and should be at a 2:1 ratio of hydrogen and carbon monoxide. In the purification process, the gas first enters a scrubber system (cooler-absorber-scrubber) where CO_2, N_2, hydrocarbons, organics, tars, and moisture are removed; after then passing through a compressor and cryogenic system, the gas finally enters the shift and synthesis reactor where additional CO_2 is removed and the 2:1 ratio of hydrogen to carbon monoxide (syngas) is achieved. Most of the scrubbed residue is recycled and consumed for reasons of economy and environmental quality.

In summary, the Moore-Canada gasifier is used for processing wood chips, while the Purox gasifier handles solid municipal waste. Since biomass (plant material) is generally similar in composition to that of the feedstock for these gasifiers, both systems can be employed to convert low-moisture crop residues to gas. The Moore-Canada gasifier seems more promising for the processing of biomass than other types (Rowell and Hokanson, 1979), and should be closely investigated for use in gasifying Illinois biomass.

Table 5.2 provides a comparison of raw gases from the Moore-Canada and Purox processes.

Most of the gas used in Illinois is of interstate origin. Among other applications, natural gas in Illinois is used to make ethylene as a feedstock for production of polyethylene and ethanol. Grain drying utilizes both LPG

Table 5.2. Composition of Raw Gases Produced by the Moore-Canada and Purox Proceses[a]

Component	Moore-Canada	Purox
Carbon Monoxide	22.8	40.0
Hydrogen	18.0	26.0
Carbon Dioxide	9.4	23.0
Methane	2.5	5.0
Hydrocarbons	0.9	5.0
Oxygen	0.5	0.5
Nitrogen	45.8	0.5

Adapted from Rowell and Hokanson, 1979.
[a]Percentage of volume, dry gas.

and natural gas and is an important seasonal energy consumer. Future energy systems will substantially contribute to corn drying, but such systems are still in the development stage. Therefore, natural gas will be needed to dry corn for many years to come. A substantial native source of gas is bituminous coal, which can be converted to fuels (thus mitigating the coal's sulfur impact). Research and development for conversion is in progress in Illinois. Other than coal, crop residues appear to be highly attractive for producing gas near grain-drying facilities. Because of such problems as transportation cost of crop residues, need for storage facilities, etc., it appears that small mobile gasifiers would be appropriate for on-site grain drying. Such mobile gasifiers are under development and will soon penetrate the market.

5.3 DIRECT COMBUSTION

The direct combustion of crop residues and food processing wastes for the generation of electricity could be made economically and environmentally attractive in Illinois by cofiring with coal. Illinois has an abundance of bituminous coal that has a high sulfur content (3.2% average). A cofired mixture, for example 90% coal and 10% residues, may reduce sulfur to acceptable levels. Furthermore, cofiring offers the feasibility of small-scale operations, reduction of transportation cost, diversity in utilization of residues, and economic benefits by minimizing required modifications to conversion plants. Burning of residues in Illinois could generate electricity, process steam, and heat for grain drying. There are certain issues involved in utilizing residues for fuel for direct combustion to generate electricity. The moisture content of the residues is high enough to make them very bulky and heavy for transportation, and energy is consumed in order to evaporate the moisture during combustion. Collection of residues is another serious problem, since the proper machinery is required and crop harvesting and residue collection are carried out almost simultaneously when farmers and equipment are very busy. Further research and development is needed to evaluate site-specific residue utilization, modify harvesting equipment for collecting crop residues, develop suitable combustion equipment for cofiring, develop small-scale operations, develop satisfactory equipment for grain drying by combustion of residues, and mitigate environmental problems arising during generation, collection, transportation, storage and combustion. The following paragraphs describe suitable examples of biomass direct combustion for electricity generation.

Research was conducted at Iowa State University (Buchele, 1978) on burning cornstalks with high-sulfur coal in boilers for producing electricity.

EPA regulations require that stack emissions from coal-burning furnaces should contain less than 1.2 lb of sulfur per million Btu. Therefore, high-sulfur coal should be mixed and cofired with lower-sulfur coal (such as Wyoming coal, which averages 0.8% S) in order to comply with EPA regulations. It is obvious that crop residues (0.06% sulfur content) could mitigate high-sulfur problems when cofired with Illinois coal.

Table 5.3 provides an economic comparison between cornstalks that are harvested and removed from the field and cornstalks that are disposed of by chopping, disking, and plowing under. Calculations have been adapted from Buchele's paper. It has been assumed that, from 2.5 tons of cornstalks produced per acre, one ton remains in the field and the rest is removed. The values given are in 1978 dollars. Comparing two options for replacing the removed nutrients (N, P, and K) with the cornstalks from the soil, namely, applying commercial fertilizers or spreading the ash from burned cornstalks (which retains P, and K, but not the N) plus additional nitrogen on the field, it appears that farmers could make a profit by selling cornstalks to furnace-boiler plants if the price (1978) was higher than \$9.46/ ton. The maximum price that utilities could pay for cornstalks (1978) was \$14.29 per ton.

Buchele (1978) presented computations concerning the value of cornstalks as a replacement for coal. According to his calculations, Wyoming coal (low S content) cost was $\$1.18/10^6$ Btu; cornstalks (delivered to utilities) cost was $\$0.87/10^6$ Btu. To meet EPA emission standards in Iowa, either Wyoming coal could be utilized with high-sulfur Iowa coal, or Iowa coal and cornstalks could be cofired. The thermal value achieved by cornstalk and coal cofiring should be greater than 34.7×10^6 Btu (less than 3 lb S per 10^6 Btu, correspondingly). Therefore, 2,483 lb of cornstalks should be cofired with each ton of Iowa coal. The calculations are listed in Table 5.4. Similar calculations for Illinois conditions indicate that cornstalks could be cofired with Illinois coal in order to reduce the sulfur emissions.

Table 5.3. Comparative Economic Evaluation between Cornstalk Disposal and Harvesting for Direct Combustion with Replacement of Fertilizer or Spreading of Ashes and Nitrogen on the Land, per Acre (1978 dollars)

Operations		$/Acre
Cornstalk Disposal:		
Chopping		5.89
Disking		2.84
Plowing Under		8.09
	TOTAL	16.82
Harvesting, Transporting, and Fertilizer Replacement:		
Harvesting 1.5 Ton, @ $10.70/Ton		19.05
Transportation of 1.5 Tons, @ $2.00/Ton		3.00
Fertilizer Replacement (N, $6.00; P, $1.62; K, $3.36)		10.98
	TOTAL	33.03
Harvesting, Transporting, and Spreading Ashes and N:		
Harvesting 1.5 Ton, @ $10.70/Ton		19.05
Transportation of 1.5 Tons, @ $2.00/Ton		3.00
Replace N in 1.5 Tons of Cornstalks		6.00
Handling and Spreading N and Ash		1.00
	TOTAL	29.05

Adapted from Buchele, 1978.

A comparative cost evaluation of the use of Illinois coal versus corn and soybean residues in an electric power plant near Piatt was conducted by Stanford Research Institute (SRI) in 1977. Table 5.5 lists processing and fuel costs in mills per kWh of coal, corncobs, field corn residue, and soybean residue. The calculations are based on a 200-MW plant. Residue costs for a plant of this size are higher than for a smaller plant because residues must be brought from greater distances to fuel the large plant. It was suggested by the SRI investigators that cofiring of residues with coal would be an attractive alternative. Cofiring of solid wastes of food processing operations with Illinois coal could also be economical, since this alternative would eliminate the need for other disposal of these wastes.

Table 5.4. Calculations for Utilizing Wyoming Coal vs. Cofiring Cornstalks and Iowa Coal (1978 dollars)

-- Wyoming coal (0.8% S; 40% moisture; 9,561 Btu/lb heating value; cost \$22.65/ton delivered to Iowa) value was: \$22.65: (9,561 Btu x 2000 lb) = \$1.18/10^6 Btu.

-- Iowa coal (5.2% S; 9,895 Btu/lb heating value; cost \$17.15 delivered to utility plant) value was: \$17.15: (9,895 Btu x 2000 lb) = \$0.87/10^6 Btu

-- One ton of Iowa coal contained: 9,895 x 2000 = 19.8 x 10^6 Btu of heat and 2000 x 0.052 = 104 lb sulfur.

-- Cornstalks and Iowa coal cofired to meet EPA standards: total heat content must be greater than (104 lb x 10^6 Btu): 3 lb = 34.7 x 10^6 Btu (3 lb of sulfur per 10^6 Btu, standard).

-- Cornstalks (0.06-0.15% S; 6 x 10^3 Btu/lb heating value) lb added to one ton of Iowa coal must be: (14.9 x 10^6): (2000 lb x 6000 Btu/lb) = 2,483 lb; (14.9 x 10^6 Btu = (34.7 x 10^6) - (19.8 x 10^6)).

-- Wyoming coal equivalent value was: 34.7 x 10^6 x \$1.18 = \$41.10.

SOURCE: Buchele, 1978.

Table 5.5. Processing and Fuel Costs for Illinois Coal and Selected Crop Residues Utilized by an Electric Power Plant, 1977 (Mills/kWh)

Residue/Fuels	Processing Cost	+	Fuel Costs	=	Busbar Power Cost
Illinois Coal[a]	19		9.5		28.5
Corncobs	18		11.9 - 12.4		29.9 - 30.4
Soybean Residue	18		19.2 - 25.5		37.2 - 43.5
Field Corn Residue	18		25.0 - 36.0		43.0 - 54.0

SOURCE: Stanford Research Institute, 1978.

[a]Processing cost for Illinois coal is higher due to sulfur scrubbing.

Another alternative use for direct combustion of crop residues is the generation of heat for grain-drying purposes. Information from the 1977 SRI economic analysis conducted in Illinois is included in Table 5.6. According to the authors, data listed in this table are similar to those concerning processes such as grain drying. The data are based on a plant that satisfies a steam demand of 50 x 10^3 lb/h and employs a boiler operating at 90% capacity and 85% thermal efficiency. Because of the small size of this plant, crop residues as a combustion feedstock for process steam appear to be economical (Stanford Research Institute, 1978). It is obvious that a more detailed analysis is needed to determine where, when, and how directly-combusted crop residues for food processing wastes will provide economic and environmental benefits for Illinois.

5.4 FERMENTATION

Ethanol can be produced from starch, cellulose, and hemicelluloses via either fermentation or acid hydrolysis, and can be used as a beverage, fuel, or feedstock for other chemicals. As a fuel, ethanol is clean and yields more energy per gallon than does methanol. Recently, the federal government has begun to encourage production of ethanol for gasohol use in order to reduce the nation's dependency on imported oil. Obviously, a vast amount of ethanol will be needed in order to convert all the gasoline used for transportation to gasohol. Because the production of ethanol presently is more costly than that for gasoline and requires large inputs of energy, there is a

Table 5.6. Processing and Fuel Costs of Coal, Oil, and Crop Residues Combusted for Process Steam in Illinois, 1977 ($/$10^3$ lb of steam)

Residue/Fuels	Process Cost	+ Fuel Cost	=	Steam Cost
Coal	3.80	1.27		5.07
Corncobs	1.90	1.82-1.88		3.72-3.78
Soybean Residue	1.90	2.36-3.28		4.26-5.18
Field Corn Residue	1.90	3.80-5.55		5.70-7.45
Oil	0.55	3.41		3.96

SOURCE: Stanford Research Institute, 1978.

degree of uncertainty about the future of gasohol. Tax incentives have been considered in order to offset high production costs, and biomass and other feedstocks are being considered for producing ethanol to make gasohol.

Fermentation -- a potential technology for making ethanol -- is defined as the anaerobic energy-yielding process in which organic substances act as both the electron donors and the electron acceptors, while anaerobic respiration is the process during which inorganic substances are the electron acceptors (Wilkinson and Rose, 1963). The main substrates of alcoholic fermentation are various hexoses and pentoses, but glucose fermentation is the most commonly studied. Various metabolic pathways of carbohydrates in microorganisms have been discovered, and pyruvic acid appears to be the key intermediate. In the fungi (e.g., yeast, etc.), the Embden-Meyerhof-Parnas (EMP) mechanism is the major glycolytic pathway and consequently the principal fermentative producer of ethanol. Ethanol is formed by (a) the glycolysis of glucose to pyruvic acid; (b) activation of pyruvic acid by the coenzyme thiamine diphosphate; (c) decarboxylation by the pyruvate decarboxylase to form acetaldehyde; and (d) reduction of acetaldehyde by the alcohol dehydrogenase, finally to form ethyl alcohol (ethanol). It appears that the macromolecules starch, cellulose, and hemicelluloses must be saccharified (decomposed to their sugar units) in order to be fermentable. Starch is saccharified more easily than are cellulose and hemicelluloses. Several saccharifying processes are under development and promising; in particular, saccharification of biomass cellulose has inherent problems (e.g., lignification and crystallinity, which are barriers to cellulolytic activity). If these problems can be solved, then the produced glucose units can be fermented directly to ethanol.

Most ethanol (90%) today is derived from ethylene, while the remainder is made from grain, molasses, and other biomass sources. In Illinois, corn grain (and possibly wheat) and food processing wastes (mostly from canneries and cheese production) are suitable for ethanol production. Crop residues are not considered useful as feedstock for ethanol production because of their seasonal generation and their utilization as livestock feed and soil conditioners. Furthermore, crop residues for ethanol production are costly to collect, require huge storage facilities, and are not very competitive with other feedstocks. These residues are better suited for methanol production.

Fermentation involves sterilization of feedstock and equipment, culture and preparation of acting microorganisms, pasteurization, fermentation, distillation, condensation, and stillage concentration. As Figure 5.5 illustrates, the corn grain, which may or may not have had its germ removed, is ground and then cooked under pressure to make mash. The mash is then saccharified into fermentable sugars (maltose) via enzymes or dilute sulfuric acid. Newer fermentation plants utilize amylase in order to continuously catalyze the saccharification (hydrolysis), while older plants employ diastase (an enzyme from barley sprouts or certain fungi [e.g., Aspergillus niger]) for this purpose. Cooked mash is placed in a vacuum cooler and then in a fermenter. Yeast is inoculated into a solution of 10 to 15% fermentable sugars, which is contained in the fermenter. Fermentation takes place at 80°F, and, since it is an exothermic process, requires cooling. The fermentation converts the solution to a beer, a fermented liquor containing 8 to 10% ethanol. This process requires 30 to 70 hr. Carbon dioxide is then removed and sometimes recovered. After fermentation is complete, the beer passes through heat exchangers and is pumped to the top of the beer still where ethanol, aldehydes, and other volatiles are distilled off. Stillage is removed from the bottom of the still, passed through a heat exchanger, and

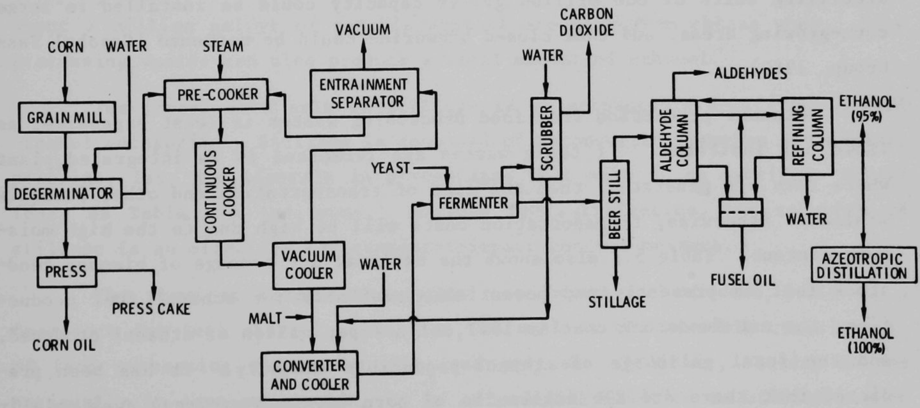


Fig. 5.5. Ethanol Production from Corn by Fermentation
(Source: Alcohol Task Group, 1980)

ultimately utilized as animal feed and as an adhesive, binder, activated carbon producer, and K-fertilizer feedstock. From the top of the beer column, the overhead beer passes through a heat exchanger and into a condenser, where the condensate (high wines, containing 50 to 60% ethanol) is concentrated. From the top of the condenser, the condensate is charged into an aldehyde column which separates the aldehydes and relevant compounds (low wines) and reruns them with subsequent batches. From the middle of the condenser the condensate runs into a rectifying or refining column, from the top of which the heads are charged into the aldehyde column, while from near the top of this column the azeotropic mixture of ethanol-water (95% ethanol) is charged into a condenser and finally taken off and stored. A 100% ethanol is obtained by adding benzene and distilling, or utilizing new additives such as glycol and glycerine and distilling.

It has been estimated that to produce 1000 gal of 95% ethanol, some 372 bu of corn, 83 bu of barley, a certain amount of yeasts, and nearly 17,000 gal of process water, 50,000 lb of steam, 42,000 gal of cooling water, and 110 kWh electricity are needed (Gasohol Task Group, 1980).

In Illinois, the Archer Daniels Midland Co. plant in Decatur produces 50 million gal of ethanol from corn each year for fuel. This company will double its capacity by 1981 (Gasohol Task Group, 1980). Additional plants in Illinois should be of smaller capacity. It has been suggested that portable distilling units of one million gal/yr capacity could be installed in large corn-growing areas, and that closed breweries could be reopened (Gasohol Task Group, 1980).

Ethanol production from food processing wastes is least expensive, as Table 5.7 indicates. If these wastes are fermented in an integrated plant where they are generated, then the cost of transportation and other items is minimal. Otherwise, transportation costs will be high due to the high moisture content. Table 5.7 also shows the national dry tonnage of biomass feedstock that is presently and potentially available for ethanol fuel production, the net feedstock cost in 1977 dollars per gallon of ethanol produced, and the total gallonage of ethanol producible annually. It has been predicted that there are 876 million bu of corn (maximum average) available in 1980 for ethanol yield (this amount is the remainder after extracting the food, feed and export demands from the total 1980 production) (U.S. Dept. of

Table 5.7. Biomass Feedstocks Presently and Potentially Available for Ethanol Production in the U.S., 1977 (1977 dollars)

	Presently Available				Potentially Available			
Biomass Feedstock	10^6 Dry Tons	10^6 Bushels	Cost ($/gal EtOH)[a]	10^6 EtOH Gal/Yr	10^6 Dry Tons	10^6 Bushels	Cost ($/gal EtOH)	10^6 EtOH Gal/Yr
Cheese Whey	0.9	--	0.22	90	0.9	--	0.22	90
Citrus Waste	1.9	--	0.80	210	1.9	--	0.80	210
Other Food Wastes	1.7	--	0.50	150	1.7	--	0.50	150
Corn	1.8	70	0.63	180	16.0	640	1.10	1660
Grain Sorghum	0.3	13	0.60	30	2.7	110	0.98	280
Wheat	--	--	--	--	11.4	420	1.36	1130
Sugar Cane	--	--	--	--	2.6	--	1.52	150
Municipal Solid Waste	--	--	--	--	43.0	--	0.20	1100
TOTAL	6.6	--	--	660	80.2	--	--	4770

Constructed from U.S. Dept. of Energy, 1979.
[a]EtOH = ethanol.

Energy, 1979). It appears that, at present, there is enough corn to produce the alcohol needed for gasohol demands. Looking at food processing wastes, about 2 million gal/yr of potable ethanol are made from cheese whey. Food processing wastes can also produce a small amount of ethanol.

The income from sale of stillage is an accountable credit for a fuel ethanol enterprise. Stillage is composed of unconverted starches and sugars, proteins, fat, and minerals in percentages that make it an excellent animal feed, as Table 5.8 indicates. Besides feed utilization, the recovery of stillage is an effective environmental-impact control measure.

The previous paragraphs present the importance of corn grain as a feedstock for fuel ethanol production, as well as the possible contribution of food processing wastes for the same purpose. Illinois, ranking second nationally in corn production, is in a favorable position to utilize a part of its corn production for fuel ethanol. Assuming that 10% of the corn grain produced in Illinois in 1978 was available for fuel ethanol production, and

Table 5.8. Approximate Composition of Dried Stillage from Corn Grain (%)

Protein (27%)		Moisture	7.5
Glutamic Acid	4.0	Fat	7.5
Leucine	3.0	Fiber	12.8
Proline	2.6	Ash (2%)	
Alanine	2.0	Sulfur	0.56
Aspartic Acid	1.7	Phosphorus	0.37
Valine	1.3	Potassium	0.15
Phenylalanine	1.2	Magnesium	0.07
Arginine	1.1	Calcium	0.05
Serine	1.0	Sodium	0.05
Glycine	1.0	Other	0.75
Isoleucine	1.0	Unconverted	
Threonine	1.0	Sugars, etc.	43.2
Other	6.1		

Constructed from Gasohol Task Group, 1980.

that 372 bu of corn could generate 1000 gal of ethanol, then the calculations show that: 120 x 10^6 bu grain corn (10% of 1,200 x 10^6 bu produced) x 2.69 (average gal of ethanol/bu corn grain) = 322.8 million gal of ethanol could be produced. The cheese-making manufactures in Illinois can also convert an appreciable amount of whey to ethanol; it is estimated that more than 1.8 million gal of ethanol could be produced from all the whey generated in Illinois in 1978. On the other hand, if all the vegetable-processing waste generated in Illinois during 1978 was fermented, nearly 15 million gal of fuel ethanol could be produced. Consequently, nearly 340 million gal of fuel ethanol was producible annually in Illinois (1978) and, mixed with gasoline (1:10 ratio), could have been used to make 3.4 x 10^9 gal of gasohol.

6 CHEMICALS DERIVED FROM CROP RESIDUES AND FOOD-PROCESSING WASTES

The solid part of crop residues and food-processing wastes consists of the natural polymers cellulose, hemicelluloses, lignin, and starch. The carbon content of these macromolecules is used as the basic block to produce plastics and other useful chemicals. Today, most of the carbon-based polymers and chemicals are derived from petroleum and natural gas which are still less expensive than non-fossil (biomass) carbon sources and, furthermore, are of a lower degree of polymerization and thus are more easily converted to plastics and chemicals. Biomass carbon sources are scattered, less collectible, and must first be depolymerized to their units in order to synthesize desirable polymers. On the other hand, the recent petroleum scarcity and price escalation have obligated researchers and government officials to comprehensively reconsider biomass sources for the production of most of the petrochemically derived materials. Cellulose, hemicelluloses, lignin, and starch are the most abundant natural polymers on earth. They are renewable, and their conversion to useful chemicals disturbs the environment much less than does the extraction and chemical conversion of fossil carbon feedstock.

As mentioned in previous sections of this report, Illinois annually generates a considerable amount of crop residues and food-processing wastes. This material, besides being convertible to energy and fuels, contains an enormous amount of lignocellulosics and starch which are sources of valuable chemicals for Illinois industries and consumers. The following paragraph list some of the potentialities of Illinois biomass residues as chemical feedstock for manufacturing.

Cellulose is extensively used. Pulp and paper industries are the main cellulose processors, making a wide range of products and by-products. Cellulose derivatives such as rayon, cellophane, cellulose acetate, cellulose acetate-propionate, carboxymethyl cellulose, and hydroxymethyl cellulose are used in various applications, including fiber production, packing, sheeting, etc. Cellulose can be decomposed to its glucose units, which in turn can be fermented to ethanol, which in turn is used in beverages and as fuel. Ethylene and butadiene which can be made from ethanol, account for nearly 60% of the building blocks of synthetic polymers (ethylene for thermoplastics and butadiene for synthetic rubber) produced in the U.S. Cellulose-derived sugars from fermentation can produce many compounds such as acetic, butyric, and lactic acids, glycerol, etc. Cellulose processing by-products can be utilized to produce feed, single cell proteins, carbon dioxide, etc.

Wood, cotton, straw, and other plant materials are used to produce cellulose. It appears that we will need more cellulose to supply manufacturing industries, thus freeing most of the petroleum that is now used to make polymers and other chemicals. Extensive research and development is needed to expand the economic base of cellulose derivation, maximize cellulose production, optimize the economics of biomass-derived cellulose, successfully compete with fossil-derived cellulose and carbon, better mitigate resulting environmental impacts, and maximize the exploitation of by-products.

Lignin utilization is very limited. The paper industry uses lignin as a source of energy (higher thermal equivalent than any other biomass constituent) and as a paper component. Smaller amounts of lignin are used to make emulsifiers, coagulants, precipitants, dispersants, thermosetting resins, antioxidants, rubber reinforcing agents, ion exchanges, desorptants, adsorptants, active carbon, soil stabilizers, fertilizer formulators, aromatic compounds, and many other useful chemicals. Phenol and related compounds, which are derived from the hydrogenation or hydrogenolysis of lignin, are needed to make phenolic resins, polyesters, etc. The hydrogenolysis of lignin yields benzene, which can be utilized to produce styrene, cyclohexane, and phthalic and terephthalic acids (both acids are now derived from xylene). Petrochemical technologies produce phenol from benzene. Lignin derivative have been used mostly in solution systems, much like the lignosulfonates from the paper industry. Since several lignin products are today derived from petrochemical sources, there are future areas where lignin utilization could be attractive, such as in phenol replacement in board production, in thermosetting resin applications, in reinforcing elastomers (increasing abrasion resistance of vulcanized rubber for tires), and in antioxidizing elastomers. While most of these areas are today covered by fossil derivatives, the world petroleum crisis will make room for the competitive use of lignin.

Hemicelluloses are used as a strengthening component in paper. They are burned for heat generation by the pulp and paper industries. These compounds can be treated microbially to produce livestock feed. Hemicellulose components are pentoses (e.g., xylose) and hexoses (e.g., mannose). Hexoses can be fermented to alcohol and acids, and pentoses can be processed to furfural and other products. Crop residues are rich in xylans and therefore a potential source of furfural. In particular, corn cobs, oat hulls, and hulls from other cereals, cereal straws, cornstalks, bagasse, cottonseeds, and various hulls, seed shells, and stalks from annual plants are rich in pentosans and can yield a considerable amount of furfural. Furfural is the building block for many furan compounds (e.g., tetrahydrofuran, used to make urethane) and is also used as a selective solvent in petroleum refining (extractive distillation to recover butadiene and isoprene) and in shell molding as a binding agent. Furfural is a solvent and can upgrade lubricating oils and can be used to make binding resins. Most furfural can be economically recovered from crop residues and can be substituted for several petrochemical intermediates.

Starch is a potential source of a pleiad of useful chemicals that includes sugar, syrups, dextrins, starchy foods, adhesives, laundry starches, building materials, coating adhesives, xanthan gum, polyurethane plastics, polyurethane foams, and other materials. For energy purposes, starch can be saccharified and finally fermented to ethanol, which can be blended with gasoline to make gasohol. Cereal grains are rich in starch, and Illinois annually produces an enormous amount of starch. One bu of corn (56 lb) contains 32 to 34 lb of starch.

From a chemical point of view, it appears that all of the aforementioned chemicals are derivable from crop residues and food processing wastes. Cornstalks and corncobs, while commonly used for livestock feed and improving soil fertility, actually can be used in an amazingly wide range of ways. The processed woody center of the corncob is highly prized as an abrasive for finishing plated metal parts and is an excellent absorbent that is used in pesticide formulations to extend their activity. The processed pith and remnants of corncobs are good roughage in cattle feed and also make a very effective and quick absorbent for oil slicks. Corncobs containing pentoses (rich in xylose) can be used to make the sweetener xylatol. Furthermore, corncobs are a potential source of furfural. Cornstalks also can produce the same chemicals. Both cornstalks and corncobs can be converted to methane, ethanol, and methanol and can provide heat, process steam, and electricity. The Quaker Oats Company has demonstrated in Illinois that corn residues are productive in furfural.

With its vast annual tonnages of biomass residues, Illinois must consider alternatives to partially exploit this valuable source of fuel, energy, and chemicals. In particular, the production of methanol, furfural, ethylene, benzene, butadiene, and xylenes must be thoroughly studied, and several technoeconomic and environmental issues must be optimized and clarified. The option of operating integrated plants that will process crop residues and food processing wastes to produce various useful chemicals must be one of high priority. Problems such as residue generation, collection, transportation, storage, pretreatment, and selection have been discussed elsewhere, and must be studied thoroughly.

7 ENVIRONMENTAL IMPLICATIONS

Utilization of crops, crop residues, and food-processing wastes to produce energy and fuels raises certain environmental problems. Crop residue removal from the fields is a serious environmental and economic disturbance. Combusting, gasifying, and fermenting of crops, crop residues, and food processing wastes add pollutants to the air, soil, and water. The prevention or mitigation of these environmental impacts is costly, time-consuming, and not always permanent. More research and development efforts are needed to solve these urgent problems. In the following paragraphs, three main biomass utilization matters concerning the environment in Illinois are analyzed: (a) effects of crop-residue removal on soil fertility; (b) effects of corn grain conversion to ethanol on the environment; and (c) food processing waste utilization and the Illinois environment.

7.1 CROP RESIDUE REMOVAL AND SOIL FERTILITY

The retention and incorporation into the soil of a certain amount of crop residues helps to maintain soil fertility and integrity at desirable levels. The problem is to determine the necessary amount of crop residues that should remain in the soil. Several researchers are now investigating this problem. It is vital that we determine the amount of residues that can be removed without damaging the soil.

Crop residues that remain in the field are a valuable source of nutrients for plants, microorganisms, and soil microfauna. The residues prevent water and wind erosion, reduce soil water evaporation and increase soil water infiltration, reduce soil temperature extremes, increase soil carbon, optimize soil texture, and maximize soil productivity.

It has been estimated that the residues from nine main crops in the United States contain approximately 4.5×10^6 tons of nitrogen, 0.5×10^6 tons of phosphorus, and 4.5×10^6 tons of potassium (Larson, 1976). This is equivalent to 40% N, 10% P, and 80% K fertilizer currently applied to all U.S. crops. Removal of all these residues would cause irreparable damage to the soil.

Soil organic matter (O.M.) tends to an equilibrium level that is determined by the cultivation system and by the removal and addition of crop residues. Cultivation disturbs this equilibrium, and the removal of crop material is in many cases critical to the maintenance of the soil O.M. equilibrium. The O.M. equilibrium determines soil productivity and integrity. Estimations have shown that the corn belt soils cultivated during the last century lost nearly one-half of their O.M. (Bartholomew et al., 1957; Brady, 1968). Soils with low O.M. content may increase their organic matter under cultivation, but soils with high organic content show a decline in O.M. under cultivation. Illinois soils, mostly rich in O.M., require the incorporation of a certain amount of crop residues.

Another serious consequence of crop residues removal is erosion caused to unprotected soils. Although the general surface slope in Illinois is between zero and two percent, in certain instances water erosion to soils without vegetation or crop residues can be serious. On the other hand, in Illinois wind erosion is not uncommon. The maximum permissible loss of soil is less than 8 tons per acre annually. The estimation of erosion losses from lands is based on the Universal Soil Loss Equation developed by Wischmeir and Smith (1978). It has been noted that, without management, erosion cannot be avoided on slopes of more than 2%.

It has been stated that in harvesting 125 bu of corn from an acre, nearly 115 lb of N, 20 lb P, and 25 lb K are simultaneously removed from the soil. If removing the whole plant, then 200 lb N, 33 lb P, and 125 lb K would be removed from the soil (Shrader, 1977). The aforementioned amounts of nutrients vary, depending on the weather and time of harvesting. In general, a high percentage of the whole plant can be removed from Illinois fields without seriously disturbing O.M. availability, but N, P, and K must be added in compensation. Several authors believe that adequate application of commercial fertilizers to a field diminishes substantially the importance of organic matter (Allison, 1973).

Removal of crop residues from the field is a fundamental issue for Illinois. Phase II of this study will comprehensively cover this matter.

7.2 ENVIRONMENTAL CONSIDERATIONS OF CORN GRAIN CONVERSION TO ETHANOL

No serious environmental problems are expected to arise because of corn grain conversion to ethanol, although the fuel used to generate steam for the process could generate air pollution problems. Such possible fuels are coal, wood, crop residues, etc. Emissions of particulates could be released from the grain elevators, from the grinding of corn, and the drying and handling of stillage. Gaseous emissions from the distillation system could add an odor to the air. Effective equipment is available to eliminate these impacts.

Wastewater from the rectifying column and from the processing of stillage have a high biological oxygen demand (20-30 mg/lb) and should be treated. These effluents come from the evaporator condensate, cooling tower, washes, and condensers. They are organic in nature and highly biodegradable. It is estimated that 12 to 55 gallons of waste are created for each gallon of ethanol produced.

Argonne investigators (Gasohol Task Group, 1980) have assessed the environmental impacts of a gasohol program and have employed three models of corn grain fermentation plants, each producing 20 million gal/yr. The first is a stand-alone plant in which whole corn grain is fermented and the stillage is dried and utilized; the second is a whole corn grain fermentation plant located next to a feedlot and the generated wet stillage is fed to cattle; and the third is appended to a corn processing plant, thus the fermentation step serves as a waste treatment, with ethanol as a by-product. Table 7.1 shows the estimated annual tonnage of residuals generated from each of these plants. Ethanol production via corn grain fermentation needs more study to monitor and control expected environmental disturbances.

7.3 FOOD-PROCESSING WASTE UTILIZATION AND THE ENVIRONMENT

Food-processing wastes are rich in carbohydrates, proteins, fats, and minerals. Therefore, their organic content and high BOD may cause water and air pollution problems. Table 7.2 lists the parts per million content in 5-day biological oxygen demand (BOD_5) and suspended solids for wastes generated from vegetable canneries and dairy-processing plants. Several techniques have been developed for use in the treatment and disposal of wastes. In most industries, separation of solids from the liquids is conducted at the time of waste generation, thus reducing the handling requirements. The solid wastes are mostly processed to make useful by-products, or are utilized as fuels; composted, and processed for feed; a small amount is disposed of. Before deciding on the utilization of food-processing wastes for fuel purposes,

Table 7.1. Residuals from Ethanol Production Processes

Residuals	Residuals[a] (Tons/Yr) Stand-Alone Corn Fermentation	Feedlot Corn Fermentation	Corn Starch Fermentation
Individual Plant[b]			
Processing Residuals			
Dust	300	150	45
Hydrocarbons	165	165	455
CO_2	65,000	65,000	180,000
BOD_5	55	40	150
Utility Residuals			
SO_2	1,100	875	2,750
NO_x	1,100	875	2,750
Fly Ash	53	45	135
Solids to Disposal			
Dust	2,400	1,200	410
Fly Ash	18,100	13,900	45,000
SO_2 Scrubber Sludge	50,000	40,000	125,000
Waste Treating Sludge	3,000	2,200	8,200
Manure (wet)	--	750,000	--
Total System[c]			
Process Residuals			
Dust	5,000	2,500	300
Hydrocarbons	2,700	2,700	2,700
CO_2	1,100,000	1,100,000	1,100,000
BOD_5	900	700	900
Utility Residuals			
SO_2	18,000	14,400	16,500
NO_x	18,000	14,400	16,500
Fly Ash	900	700	800
Solids to Disposal			
Dust	40,000	20,000	2,500
Fly Ash	300,000	230,000	275,000
SO_2 Scrubber Sludge	825,000	660,000	750,000
Waste Treating Sludge	50,000	36,000	49,000
Manure (wet)	--	14,400,000	--

Adapted from Gasohol Task Group, 1980.

[a]Residuals are the gaseous, liquid, and solid emissions from the production process when environmental controls are in use.

[b]Individual plant capacity of: 20 million gal/yr for stand-alone and feedlot systems and 55 million gal/yr for corn starch method.

[c]Total system capacity of 330 million gal/yr (for the stand-alone and feedlot systems, 16.5 rather than 17 plants were used as a basis for estimating emissions).

Table 7.2. Biological Oxygen Demand and Suspended Solids in Vegetable Canning and Milk Processing Wastes (Parts Per Million)

Wastes	BOD_5	Suspended Solids
Corn, Whole Kernel	1,123-6,025	300-4,000
Corn, Cream	623	302
Beans	160-600	60-85
Asparagus	100	30
Tomatoes, Whole	570-4,000	190-2,000
Tomato Juice	178-3,800	170-1,168
Milk products	674	387

Constructed from Parker and Litchfield, 1962; and Hurwitz and Jonas, 1956.

all environmental implications should be studied. Fermentation of these wastes to produce ethanol has similar environmental consequences to those discussed in Section 7.2.

Table 7.2. [illegible] Oxygen Demand and [illegible] in [illegible] and [illegible]
[illegible]

[illegible]	[illegible]	Suspended [illegible]
[illegible]	1,[illegible]-6,725	[illegible]
[illegible]	6[illegible]	[illegible]
[illegible]	160-600	[illegible]
[illegible]	[illegible]00	[illegible]
[illegible]	570-[illegible],000	[illegible]
Tomato juice	178-2[illegible],000	[illegible]
[illegible] products	[illegible]	[illegible]

Compiled from [illegible] and Litchfield, [illegible] and [illegible] and [illegible], [illegible]

[illegible] environmental implications should be [illegible]. [illegible] [illegible] [illegible] [illegible] not [illegible] environmental [illegible] [illegible] [illegible] in section [illegible].

8 CONCLUSIONS AND RECOMMENDATIONS

1. The highly productive land of Illinois, which is influenced by a favorable combination of ecological and socioeconomic factors, generates an impressive amount of crop residues and places Illinois in the leading position among the states in regard to conversion of a portion of these residues to usable forms of energy.

2. Crops, crop residues, and wastes from food processing operations are potential biomass resources for fuel and chemicals production in Illinois. The state can strengthen its economy substantially by further development of industries that produce biofuels and biomass-derived chemicals.

3. The use of better varieties and the application of continuously improving soil and crop management practices in Illinois promise that yields will keep rising; consequently the amount of available crop residue will also continue to rise.

4. Utilization of crop residues for fuel production and energy is accompanied by a number of problems, including generation, collection, transportation, storage, conversion to energy and fuels, soil fertility and erosion, environmental issues, economic consequences, energy balance, and even sociopolitical and institutional matters. These problems all require investigation and solution.

5. Nearly 39.2 million dry tons of residues were produced in Illinois during 1978 from seven main annual crops. Of this amount about 33.5 million dry tons (85.5%) were collectible, and close to 23.6 million dry tons were wasted residues. The corn crop generated nearly 19.5 million dry tons of residues, while soybeans produced about 16.5 million dry tons. In 1978, McLean County was the leader in both corn and soybean residue generation, while Champaign County was second.

6. The thermal equivalent energy of crop residues in Illinois (1978) was estimated to be 658 x 10^{12} Btu (0.66 Quad) and that of "wasted" residues 397 x 10^{12} Btu (0.4 Quad). Energy released from "wasted" residues could replace 17.7% of the oil that is imported from foreign countries, processed in Illinois, and partially consumed within the state. Alternatively, this energy could easily cover 73% of electrical power needs or 15% of natural gas requirements.

7. Both economic and energy evaluations of Illinois crop residues are needed.

8. Important wastes for fuel production are those generated from corn and bean canneries and cheesemaking operations in Illinois. Estimated waste generated by vegetable processing in 1978 was 163 million tons (of which 153 million tons are utilized as by-product) from sweet corn, and 5 million tons (2.5 million tons utilized as by-product) from snap beans. During the same year, 0.5 million tons of whey were generated during the making of cheese.

9. If the nonutilized waste generated in 1978 during vegetable processing was converted, it could produce nearly 1.2 million gal of ethanol. Assuming that 40% of the lactose contained in the whey produced in Illinois in 1978 was fermented, more than 1.8 million gal of ethanol could be generated.

10. A certain amount of crop residues should be gasified to produce methane. Of the variety of gasifiers available, the most promising should be selected and demonstrated by the state.

11. Cofiring low-moisture-content crop residues and food processing wastes with Illinois coal to produce electricity, process steam, and heat for grain drying seems to be an attractive possibility.

12. Assuming that 10% of corn grain produced in Illinois in 1978 was available and fermented, then 323 million gal of ethanol could be produced.

13. Cellulose, hemicelluloses, lignin, and starch contained in crop grain, crop residues, and food processing wastes could be processed to generate several useful chemicals utilized by Illinois buyers. Extensive research and development are needed to expand the economic base of lignocellulosics and starch derivation, and to develop better technologies for producing chemicals. In particular, the production of methanol, furfural, ethylene, benzene, butadiene, and xylenes in Illinois must be thoroughly examined.

14. A comprehensive evaluation is needed of the energy, chemical, and economic values contained in forest residues, pulp and paper milling residues, wood-manufacturing residues, and farm animal wastes in Illinois.

15. A thorough evaluation should be conducted of the state's less exploitable lands to be utilized for biomass production.

16. A comparative technoeconomic and environmental analysis of Illinois biomass conversion to energy must be carried out.

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APPENDIX
AGRICULTURAL STATISTICS
BY COUNTY FOR ILLINOIS, 1978

Table A-1. Illinois Corn Acreage, Production, Value, Residue, and Residue Btu Content, 1978[a]

County	Crop: Acres Harvested for Grain[b] (10^3)	Crop: Production (10^3 Bushels)[b]	Crop: Total Value (\$$10^3$, 1978)	Residue: Residue Dry Tons (10^3)	Residue: "Wasted" Residue Dry Tons (10^3)	Residue: Energy Value of "Wasted" Residues (10^9 Btu)
Adams	107.1	10,247.2	22,031.5	167.3	67.8	1,139.0
Alexander	9.4	855.6	1,839.5	14.0	5.7	95.8
Bond	37.7	3,293.7	7,081.5	53.8	21.8	366.2
Boone	69.2	8,424.1	18,111.8	137.5	55.7	935.8
Brown	35.5	3,468.1	7,456.4	56.6	22.9	384.7
Bureau	273.3	32,193.7	69,216.5	525.5	212.8	3,575.0
Calhoun	19.9	1,981.2	4,259.6	32.3	13.1	220.1
Carroll	127.1	13,576.3	29,189.0	221.6	89.7	1,507.0
Cass	72.1	7,617.4	16,377.4	124.3	50.3	845.0
Champaign	286.9	38,062.6	81,834.6	621.3	251.6	4,226.9
Christian	171.8	19,023.4	40,900.3	310.5	125.8	2,113.4
Clark	71.2	8,862.9	19,055.2	144.6	58.6	984.5
Clay	46.4	4,308.2	9,262.6	70.3	28.5	478.8
Clinton	56.4	5,133.8	11,037.7	83.8	33.9	569.5
Coles	123.6	15,259.5	32,807.9	249.1	100.9	1,695.1
Cook	16.7	1,599.7	3,439.4	26.1	10.6	178.1
Crawford	74.2	8,327.8	17,904.8	136.0	55.1	925.7
Cumberland	51.4	5,768.9	12,403.1	94.2	38.2	641.8
De Kalb	201.9	25,384.2	54,576.0	414.4	167.8	2,819.0
De Witt	117.3	14,458.6	31,086.0	236.0	95.6	1,606.1
Douglas	115.7	14,638.3	31,472.3	239.0	96.8	1,626.2
Du Page	18.8	2,119.8	4,557.6	34.6	14.0	235.2
Edgar	141.3	18,309.7	39,365.9	298.9	121.1	2,034.5
Edwards	40.4	2,947.9	6,338.0	48.1	19.5	327.6
Effingham	58.5	6,565.7	14,116.3	107.2	43.4	729.1
Fayette	55.9	5,019.1	10,791.1	81.9	33.2	557.8
Ford	141.1	16,559.6	35,603.1	270.3	109.5	1,839.6
Franklin	26.6	1,580.1	3,397.2	25.8	10.5	176.4
Fulton	133.6	12,782.7	27,482.8	208.7	84.5	1,419.6
Gallatin	59.1	4,446.9	9,560.8	72.6	29.4	493.9
Greene	79.8	8,187.7	17,603.6	133.7	54.1	908.9
Grundy	112.0	12,293.3	26,430.6	200.7	81.3	1,365.8
Hamilton	39.4	2,262.5	4,864.4	36.9	14.9	250.3
Hancock	140.2	14,685.0	31,572.8	239.7	97.1	1,631.3
Hardin	4.9	291.1	625.9	4.8	1.9	31.9
Henderson	96.8	13,063.9	28,087.4	213.3	86.4	1,451.5
Henry	243.9	28,730.7	61,771.0	469.0	189.9	3,190.3
Iroquois	328.7	36,899.2	79,333.3	602.3	243.9	4,097.5
Jackson	29.2	2,303.5	4,952.6	37.6	15.2	255.4
Jasper	64.3	6,954.3	14,951.7	113.5	46.0	772.8

Table A-1. (contd.)

County	Crop: Acres Harvested for Grain[b] (10^3)	Crop: Production (10^3 Bushels)[b]	Crop: Total Value ($\$10^3$, 1978)	Residue: Residue Dry Tons (10^3)	Residue: "Wasted" Residue Dry Tons (10^3)	Residue: Energy Value of "Wasted" Residues (10^9 Btu)
Jefferson	38.6	3,057.3	6,573.2	49.9	20.2	339.4
Jersey	41.2	4,269.1	9,178.6	69.7	28.2	473.8
Jo Daviess	74.9	8,299.6	17,844.1	135.5	54.9	922.3
Johnson	16.5	1,034.7	2,224.6	16.9	6.8	114.2
Kane	118.2	14,625.0	31,443.8	238.7	96.7	1,632.3
Kankakee	180.1	20,401.5	43,863.2	333.0	134.9	2,266.3
Kendall	90.7	9,774.3	21,014.7	159.6	64.6	1,085.3
Knox	183.6	22,004.4	47,309.5	359.2	145.5	2,444.4
Lake	24.2	2,318.2	4,984.1	37.8	15.3	257.0
La Salle	312.6	34,623.2	74,439.9	565.2	228.9	3,845.5
Lawrence	78.1	7,570.3	16,276.1	123.6	50.0	840.0
Lee	208.8	24,596.0	52,881.4	401.6	162.6	2,731.7
Livingston	284.9	34,017.5	73,137.6	555.3	224.9	3,778.3
Logan	184.1	20,442.0	43,950.3	333.7	135.1	2,269.7
McDonough	128.7	13,869.3	29,819.0	226.4	91.7	1,540.6
McHenry	123.8	12,970.8	27,887.2	211.7	85.7	1,439.8
McLean	360.3	45,145.2	97,062.2	737.0	298.5	5,014.8
Macon	159.0	19,598.6	42,137.0	319.9	129.6	2,177.3
Macoupin	116.1	12,384.0	26,625.6	202.2	81.9	1,375.9
Madison	68.6	6,550.8	14,084.2	106.9	43.3	727.4
Marion	39.3	2,967.3	6,379.7	48.4	19.6	329.3
Marshall	108.3	11,032.4	23,719.7	180.1	72.9	1,224.7
Mason	113.3	11,080.1	23,822.2	180.9	73.3	1,231.4
Massac	20.7	1,598.5	3,436.8	26.1	10.6	178.1
Menard	75.6	8,779.5	18,875.9	143.3	58.0	974.4
Mercer	160.6	18,276.9	39,295.3	298.4	120.9	2,031.1
Monroe	32.9	3,427.3	7,368.7	55.9	22.6	379.7
Montgomery	99.8	9,732.9	20,925.7	158.9	64.4	1,081.9
Morgan	109.2	12,424.5	26,712.7	202.8	82.1	1,379.3
Moultrie	89.0	10,624.6	22,842.9	173.4	70.2	1,179.4
Ogle	217.7	25,644.4	55,135.5	418.6	169.5	2,847.6
Peoria	114.7	11,918.1	25,623.9	194.6	78.7	1,322.2
Perry	28.6	2,256.2	4,850.8	36.8	14.9	250.3
Piatt	141.4	19,192.2	41,263.2	313.3	126.9	2,131.9
Pike	120.3	12,465.4	26,800.6	203.5	82.4	1,384.3
Pope	12.8	760.4	1,634.9	12.4	5.0	84.0
Pulaski	9.7	882.9	1,898.2	14.4	5.8	97.4
Putnam	44.6	4,229.7	9,093.9	69.0	27.9	468.7
Randolph	44.6	3,924.4	8,437.5	64.1	26.0	436.8
Richland	57.4	5,856.6	12,591.7	95.6	38.7	650.2

Table A-1. (contd.)

	Crop			Residue		
County	Acres Harvested for Grain[b] (10^3)	Production (10^3 Bushels)[b]	Total Value (\$$10^3$, 1978)	Residue Dry Tons (10^3)	"Wasted" Residue Dry Tons (10^3)	Energy Value of "Wasted" Residues (10^9 Btu)
Rock Island	86.8	9,531.6	20,492.9	155.6	63.0	1,058.4
St. Clair	63.8	6,710.9	14,428.4	109.6	44.4	745.9
Saline	42.1	2,500.9	5,376.9	40.8	16.5	277.2
Sangamon	200.7	22,631.3	48,657.3	369.4	149.6	2,513.3
Schuyler	59.7	5,411.4	11,634.5	88.3	35.8	601.4
Scott	37.5	3,961.9	8,518.1	64.7	26.2	440.2
Shelby	153.7	16,466.4	35,402.8	268.8	108.9	1,829.5
Stark	106.8	12,185.2	26,198.2	198.9	80.6	1,354.1
Stephenson	154.6	17,594.1	37,827.3	287.2	116.3	1,953.8
Tazewell	181.0	21,204.1	45,588.8	346.1	140.2	2,355.4
Union	13.6	756.5	1,626.5	12.3	5.0	84.0
Vermilion	217.6	25,981.8	55,860.9	424.1	171.8	2,886.2
Wabash	45.3	4,484.9	9,642.5	73.2	29.6	497.3
Warren	169.9	20,533.7	44,147.5	335.2	135.8	2,281.4
Washington	62.7	5,707.3	12,270.7	93.2	37.7	633.4
Wayne	75.3	5,964.0	12,822.6	97.4	39.5	663.6
White	84.8	5,877.0	12,635.6	95.9	38.8	651.8
Whiteside	232.6	25,774.2	55,414.5	420.7	170.4	2,862.7
Will	142.4	14,919.6	32,077.1	243.5	98.6	1,656.5
Williamson	12.6	828.3	1,780.8	13.5	5.5	92.4
Winnebago	94.7	10,588.1	22,764.4	172.8	70.0	1,176.0
Woodford	159.0	18,302.8	39,351.0	298.8	121.0	2,032.0
ILLINOIS	10,730.0	1,191,030.0	2,560,714.5	19,442.1	7,873.9	132,281.52

[a]All calculations are made with conversion factors given in Table 3.1.

[b]Illinois Department of Agriculture (1979).

Table A-2. Illinois Soybean Acreage, Production, Value, Residue, and Residue Btu Content, 1978[a]

County	Crop: Acres Harvested for Grain[b] (10^3)	Crop: Production (10^3 Bushels)[b]	Crop: Total Value ($\$10^3$, 1978)	Residue: Residue Dry Tons (10^3)	Residue: "Wasted" Residue Dry Tons (10^3)	Residue: Energy Value of "Wasted" Residues (10^9 Btu)
Adams	134.0	3,981.9	26,479.6	217.4	173.9	2,921.5
Alexander	43.0	1,055.5	7,019.1	57.6	46.1	774.5
Bond	72.0	1,923.0	12,788.0	105.0	84.0	1,411.2
Boone	38.5	1,285.8	8,550.6	70.2	56.2	944.2
Brown	41.5	1,315.4	8,747.4	71.8	57.4	964.3
Bureau	110.0	4,220.3	28,065.0	230.4	184.3	3,096.2
Calhoun	10.0	306.6	2,038.9	16.7	13.4	225.1
Carroll	10.3	364.8	2,425.9	19.9	15.9	267.1
Cass	68.0	2,320.6	15,432.0	126.7	101.4	1,703.5
Champaign	255.0	10,000.3	66,502.0	546.0	436.8	7,338.2
Christian	177.0	6,565.8	43,662.6	358.5	287.0	4,821.6
Clark	120.0	4,286.9	28,507.9	234.1	187.3	3,146.6
Clay	103.0	2,606.4	17,332.6	142.3	113.8	1,911.8
Clinton	81.5	2,080.5	13,835.3	113.6	90.9	1,527.1
Coles	114.0	4,355.4	28,963.4	237.8	190.2	3,195.4
Cook	27.5	742.9	4,940.3	40.6	32.5	546.0
Crawford	85.0	2,614.8	17,388.4	142.8	114.2	1,918.6
Cumberland	69.0	2,396.5	15,936.7	130.8	104.6	1,757.3
De Kalb	114.5	4,217.8	28,048.4	230.3	184.2	3,094.6
De Witt	89.0	3,506.7	23,319.6	191.5	153.2	2,573.8
Douglas	123.0	4,699.3	31,250.3	256.6	205.3	3,449.0
Du Page	18.5	636.0	4,229.4	34.7	27.8	467.0
Edgar	142.0	5,425.2	36,077.6	296.2	237.0	3,981.6
Edwards	38.0	1,036.4	6,892.1	56.6	45.3	761.0
Effingham	90.0	2,590.0	17,223.5	141.4	113.1	1,900.1
Fayette	140.0	3,473.2	23,096.8	189.6	151.7	2,548.6
Ford	134.0	4,855.9	32,291.7	265.1	212.1	3,563.3
Franklin	80.0	1,480.6	9,846.0	80.8	64.6	1,085.3
Fulton	96.0	3,280.6	21,816.0	179.1	143.3	2,407.4
Gallatin	57.5	1,400.2	9,311.3	76.5	61.2	1,028.2
Greene	89.0	2,993.3	19,905.4	163.4	130.7	2,195.8
Grundy	82.0	2,416.5	16,069.7	131.9	105.5	1,772.4
Hamilton	98.0	1,718.3	11,426.7	93.8	75.0	1,260.0
Hancock	142.0	4,993.3	33,205.4	272.6	218.1	3,664.1
Hardin	1.0	24.4	162.3	1.3	1.0	16.8
Henderson	44.5	1,741.1	11,578.3	95.1	76.1	1,278.5
Henry	81.0	3,028.1	20,136.9	165.3	132.2	2,221.0
Iroquois	269.0	9,347.5	62,160.9	510.4	408.3	6,859.4
Jackson	78.0	2,144.3	14,259.6	117.1	93.7	1,574.2
Jasper	127.0	3,969.9	26,399.8	216.8	173.4	2,913.1

Table A-2. (contd.)

	Crop			Residue		
County	Acres Harvested for Grain[b] (10^3)	Production (10^3 Bushels)[b]	Total Value (\$$10^3$, 1978)	Residue Dry Tons (10^3)	"Wasted" Residue Dry Tons (10^3)	Energy Value of "Wasted" Residues (10^9 Btu)
Jefferson	102.0	2,285.2	15,196.6	124.8	99.8	1,676.6
Jersey	61.0	1,991.2	13,214.5	108.7	87.0	1,461.6
Jo Daviess	4.7	148.0	984.2	8.1	6.5	109.2
Johnson	13.5	291.6	1,939.1	15.9	12.7	213.4
Kane	68.5	2,422.4	16,109.0	132.3	105.8	1,777.4
Kankakee	145.0	4,750.7	31,592.2	259.4	207.5	3,486.0
Kendall	65.0	1,915.5	12,738.1	104.6	83.7	1,406.2
Knox	72.0	2,852.7	18,970.5	155.8	124.6	2,093.3
Lake	24.0	660.1	4,389.7	36.0	28.8	483.8
La Salle	228.0	7,726.9	51,383.9	421.9	337.5	5,670.0
Lawrence	50.0	1,339.7	8,909.0	73.1	58.5	982.8
Lee	108.0	3,771.8	25,082.5	205.9	164.7	2,767.0
Livingston	271.0	9,686.0	64,411.9	528.9	432.1	7,108.1
Logan	142.0	5,455.1	36,276.4	297.8	238.2	4,001.8
McDonough	100.0	3,664.9	24,371.6	200.1	160.1	2,689.7
McHenry	46.5	1,438.8	9,568.0	78.6	62.9	1,056.7
McLean	264.0	10,531.9	70,037.1	575.0	460.0	7,728.0
Macon	133.0	5,043.9	33,541.9	275.4	220.3	3,701.0
Macoupin	176.0	5,571.1	37,047.8	304.2	243.4	4,089.1
Madison	130.0	3,857.8	25,654.4	210.6	168.5	2,830.8
Marion	118.0	2,517.6	16,742.0	137.5	110.0	1,848.0
Marshall	59.0	1,976.0	13,140.4	107.9	86.3	1,449.8
Mason	96.0	3,309.7	22,009.5	180.7	144.6	2,429.3
Massac	27.5	750.0	4,987.5	41.0	32.8	551.0
Menard	65.0	2,529.1	16,818.5	138.1	110.5	1,856.4
Mercer	44.5	1,663.6	11,062.9	90.8	72.6	1,219.7
Monroe	50.0	1,570.9	10,446.5	85.8	68.6	1,152.5
Montgomery	168.0	5,151.7	34,258.8	281.3	225.0	3,780.0
Morgan	110.0	4,189.2	27,858.2	228.7	183.0	3,074.4
Moultrie	84.0	3,125.9	20,787.2	170.7	136.6	2,294.9
Ogle	65.0	2,398.0	15,946.7	130.9	104.7	1,759.0
Peoria	58.0	1,999.6	13,297.3	109.2	87.4	1,468.3
Perry	70.5	1,661.3	11,047.6	90.7	72.6	1,219.7
Piatt	113.0	4,375.4	29,096.4	238.9	191.1	3,210.5
Pike	105.0	3,531.4	23,483.8	192.8	154.2	2,590.6
Pope	11.0	278.6	1,852.7	15.2	12.2	205.0
Pulaski	29.5	782.0	5,200.3	42.7	34.2	574.6
Putnam	21.0	702.4	4,671.0	38.4	30.7	515.8
Randolph	67.0	1,973.5	13,123.8	107.8	86.2	1,448.2
Richland	74.0	2,056.1	13,673.1	112.3	89.8	1,508.6

Table A-2. (contd.)

County	Crop: Acres Harvested for Grain[b] (10^3)	Crop: Production (10^3 Bushels)[b]	Crop: Total Value ($\$10^3$, 1978)	Residue: Residue Dry Tons (10^3)	Residue: "Wasted" Residue Dry Tons (10^3)	Residue: Energy Value of "Wasted" Residues (10^9 Btu)
Rock Island	25.0	910.0	6,051.5	49.7	39.8	668.6
St. Clair	123.0	4,166.5	27,707.2	227.5	182.0	3,057.6
Saline	47.5	1,041.0	6,922.7	56.8	45.4	762.7
Sangamon	190.0	7,424.1	49,370.3	405.4	324.3	5,448.2
Schuyler	61.0	1,812.7	12,054.5	99.0	79.2	1,330.6
Scott	39.0	1,408.1	9,363.9	76.9	61.5	1,033.2
Shelby	156.0	5,418.2	36,031.0	295.8	236.6	3,974.9
Stark	40.0	1,457.8	9,694.4	79.6	63.7	1,070.2
Stephenson	18.0	637.5	4,239.4	34.8	27.8	467.0
Tazewell	89.0	3,331.4	22,153.8	181.9	145.5	2,444.4
Union	34.0	867.9	5,771.5	47.4	37.9	636.7
Vermilion	208.0	7,640.8	50,811.3	417.2	333.8	5,607.8
Wabash	34.5	974.6	6,481.1	53.2	42.6	715.7
Warren	69.0	2,836.4	18,862.1	154.9	123.9	2,081.5
Washington	137.0	3,564.5	23,703.9	194.6	155.7	2,615.8
Wayne	147.0	3,150.0	20,947.5	172.0	137.6	2,311.7
White	101.0	2,312.0	15,374.8	126.2	101.0	1,696.8
Whiteside	62.5	2,213.5	14,719.8	120.9	96.7	1,624.6
Will	127.0	3,742.6	24,888.3	204.3	163.4	2,745.1
Williamson	23.0	451.6	3,003.1	24.7	19.8	332.6
Winnebago	30.0	1,003.5	6,673.3	54.8	43.8	735.8
Woodford	95.0	3,556.0	23,647.4	194.2	155.4	2,610.7
ILLINOIS	9,190.0	303,270.0	2,016,745.5	16,558.5	13,252.9	222,648.7

[a]All calculations are made with conversion factors given in Table 3.1.

[b]Illinois Department of Agriculture (1979).

Table A-3. Illinois Wheat Acreage, Production, Value, Residue, and Residue Btu Content, 1978[a]

County	Crop: Acres Harvested for Grain[b] (10^3)	Crop: Production (10^3 Bushels)[b]	Crop: Total Value ($\$10^3$, 1978)	Residue: Residue Dry Tons (10^3)	Residue: "Wasted" Residue Dry Tons (10^3)	Residue: Energy Value of "Wasted" Residues (10^9 Btu)
Adams	14.5	459.5	1,401.5	31.4	26.4	443.5
Alexander	4.8	168.5	513.9	11.5	9.7	163.0
Bond	22.5	803.4	2,450.4	54.9	46.1	774.5
Boone	1.7	68.4	208.6	4.7	3.9	65.5
Brown	2.5	76.7	233.9	5.2	4.4	73.9
Bureau	2.5	90.9	277.2	6.2	5.2	87.4
Calhoun	4.5	176.5	538.3	12.1	10.2	171.4
Carroll	0.4	15.4	47.0	1.1	0.9	15.1
Cass	7.0	232.3	708.5	15.9	13.4	225.1
Champaign	5.0	197.7	603.0	13.5	11.3	189.8
Christian	8.0	293.7	895.8	20.1	16.9	283.9
Clark	16.0	574.4	1,751.9	39.2	32.9	552.7
Clay	21.0	753.9	2,299.4	51.5	43.3	727.4
Clinton	28.5	1,086.1	3,312.6	74.2	62.3	1,046.6
Coles	4.7	182.8	557.5	12.5	10.5	176.4
Cook	1.4	56.4	172.0	3.9	3.3	55.4
Crawford	17.5	637.0	1,942.9	43.5	36.5	613.2
Cumberland	9.0	350.0	1,067.5	23.9	20.1	337.7
De Kalb	1.3	52.3	159.5	3.6	3.0	50.4
De Witt	1.2	42.8	130.5	2.9	2.4	40.3
Douglas	3.3	121.8	371.5	8.3	7.0	117.6
Du Page	1.1	46.4	141.5	3.2	2.7	45.4
Edgar	9.5	407.4	1,242.6	27.8	23.4	393.1
Edwards	9.0	335.2	1,022.4	22.9	19.2	322.6
Effingham	21.0	816.7	2,490.9	55.8	46.9	787.9
Fayette	29.0	954.4	2,910.9	65.2	54.8	920.6
Ford	1.0	35.1	107.1	2.4	2.0	33.6
Franklin	10.0	362.4	1,105.3	24.8	20.8	349.4
Fulton	4.4	135.1	412.1	9.2	7.7	129.4
Gallatin	10.0	382.5	1,166.6	26.1	21.9	367.9
Greene	14.5	605.2	1,845.9	41.3	34.7	583.0
Grundy	0.8	31.4	95.8	2.1	1.8	30.2
Hamilton	19.0	755.4	2,304.0	51.6	43.3	727.4
Hancock	5.0	148.5	452.9	10.1	8.5	142.8
Hardin	0.1	3.5	10.7	0.2	0.2	3.4
Henderson	1.2	38.0	115.9	2.6	2.2	37.0
Henry	0.7	27.6	84.2	1.9	1.6	26.9
Iroquois	2.6	93.7	285.8	6.4	5.4	90.7
Jackson	18.0	604.7	1,844.3	41.3	34.7	583.0
Jasper	17.0	627.3	1,913.3	42.8	36.0	604.8

Table A-3. (contd.)

County	Crop: Acres Harvested for Grain[b] (10^3)	Crop: Production (10^3 Bushels)[b]	Crop: Total Value ($\$10^3$, 1978)	Residue: Residue Dry Tons (10^3)	Residue: "Wasted" Residue Dry Tons (10^3)	Residue: Energy Value of "Wasted" Residues (10^9 Btu)
Jefferson	20.5	846.0	2,580.3	57.8	48.6	816.5
Jersey	17.0	735.2	2,242.4	50.2	42.2	709.0
Jo Daviess	0.4	16.2	49.4	1.1	0.9	15.1
Johnson	2.8	92.7	282.7	6.3	5.3	89.0
Kane	1.4	57.7	176.0	3.9	3.3	55.4
Kankakee	3.0	111.2	339.2	7.6	6.4	107.5
Kendall	1.1	44.3	135.1	3.0	2.5	42.0
Knox	1.3	50.2	153.1	3.4	2.9	48.7
Lake	2.5	90.8	276.9	6.2	5.2	87.4
La Salle	1.3	46.0	140.3	3.1	2.6	43.7
Lawrence	9.5	355.3	1,083.7	24.3	20.4	342.7
Lee	1.7	61.8	188.5	4.2	3.5	58.8
Livingston	1.0	39.1	119.3	2.7	2.3	38.6
Logan	1.8	78.6	239.7	5.4	4.5	75.6
McDonough	2.4	90.3	275.4	6.2	5.2	87.4
McHenry	1.4	55.0	167.8	3.8	3.2	53.8
McLean	1.1	45.8	139.7	3.1	2.6	43.7
Macon	2.6	100.6	306.8	6.9	5.8	97.4
Macoupin	27.0	1,113.4	3,395.9	76.0	63.8	1,071.8
Madison	42.0	1,563.1	4,767.5	106.8	89.7	1,507.0
Marion	28.0	1,047.0	3,193.3	71.5	60.1	1,009.7
Marshall	1.5	52.1	158.9	3.6	3.0	50.4
Mason	17.1	542.8	1,655.5	37.1	31.2	542.2
Massac	1.9	68.8	209.8	4.7	4.0	67.2
Menard	2.1	83.3	254.1	5.7	4.8	80.6
Mercer	0.9	39.1	119.3	2.7	2.3	38.6
Monroe	30.5	1,254.1	3,825.0	85.7	72.0	1,209.6
Montgomery	32.0	1,206.9	3,681.0	82.4	69.2	1,162.6
Morgan	7.0	309.8	944.9	21.2	17.8	299.0
Moultrie	3.0	125.7	383.4	8.6	7.2	121.0
Ogle	3.3	136.6	416.6	9.3	7.8	131.0
Peoria	5.0	183.5	559.7	12.5	10.5	176.4
Perry	13.5	453.6	1,383.5	31.0	26.0	436.8
Piatt	1.2	50.5	154.0	3.4	2.9	48.7
Pike	11.5	428.0	1,305.4	29.2	24.5	411.6
Pope	1.8	59.8	182.4	4.1	3.4	57.1
Pulaski	5.0	175.5	535.3	12.0	10.1	169.7
Putnam	1.0	32.3	98.5	2.2	1.8	30.2
Randolph	31.0	1,134.8	3,461.1	77.5	65.1	1,093.7
Richland	11.5	447.3	1,364.3	30.6	25.7	431.8

Table A-3. (contd.)

	Crop			Residue		
County	Acres Harvested for Grain[b] (10^3)	Production (10^3 Bushels)[b]	Total Value (\$$10^3$, 1978)	Residue Dry Tons (10^3)	"Wasted" Residue Dry Tons (10^3)	Energy Value of "Wasted" Residues (10^9 Btu)
Rock Island	0.4	15.0	45.8	1.0	0.8	13.4
St. Clair	49.0	2,113.1	6,445.0	144.3	121.2	2,036.2
Saline	7.0	260.7	795.1	17.8	15.0	252.0
Sangamon	5.0	196.1	598.1	13.4	11.3	189.8
Schuyler	6.3	174.7	532.8	11.9	10.0	168.0
Scott	4.0	152.9	466.3	10.4	8.7	146.2
Shelby	24.0	933.4	2,846.9	63.8	53.6	900.5
Stark	0.5	19.8	60.4	1.4	1.2	20.2
Stephenson	1.0	46.5	141.8	3.2	2.7	45.4
Tazewell	4.3	140.7	429.1	9.6	8.1	135.1
Union	6.2	217.6	663.7	14.9	12.5	210.0
Vermilion	4.2	678.7	2,070.0	46.4	39.0	655.2
Wabash	6.7	236.0	719.8	16.1	13.5	226.8
Warren	0.4	14.7	44.8	1.0	0.8	13.4
Washington	46.0	1,937.6	5,909.7	132.3	111.1	1,866.5
Wayne	21.0	750.4	2,288.7	51.3	43.1	724.1
White	31.0	1,279.3	3,901.9	87.4	73.4	1,233.1
Whiteside	1.5	63.7	194.3	4.4	3.7	62.2
Will	3.0	109.1	332.8	7.5	6.3	105.8
Williamson	2.7	89.4	272.7	6.1	5.1	85.7
Winnebago	2.2	97.8	298.3	6.7	5.6	94.1
Woodford	1.8	64.3	196.1	4.4	3.7	62.2
ILLINOIS	930.0	34,340.0	107,787.0	2,413.7	2,027.5	34,062.0

[a]All calculations are made with conversion factors given in Table 3.1.
[b]Illinois Department of Agriculture (1979).

Table A-4. Illinois Oat Acreage, Production, Value, Residue, and Residue Btu Content, 1978[a]

	Crop			Residue		
County	Acres Harvested for Grain[b] (10^3)	Production (10^3 Bushels)[b]	Total Value ($\$10^3$, 1978)	Residue Dry Tons (10^3)	"Wasted" Residue Dry Tons (10^3)	Energy Value of "Wasted" Residues (10^9 Btu)
Adams	2.3	105.0	131.3	4.55	2.90	48.7
Alexander	0.05	1.7	2.1	0.07	.04	0.7
Bond	0.35	15.4	19.3	0.67	.43	7.2
Boone	5.5	288.4	360.5	12.49	7.97	133.9
Brown	0.8	32.5	40.6	1.41	.90	15.1
Bureau	9.5	570.1	712.6	24.69	15.75	264.6
Calhoun	0.2	8.2	10.3	0.36	.23	3.8
Carroll	10.0	559.8	699.8	24.24	15.47	259.9
Cass	0.4	17.2	21.5	0.74	.47	7.9
Champaign	2.5	162.0	202.5	7.01	4.47	75.1
Christian	1.6	102.9	128.6	4.46	2.85	47.9
Clark	0.35	15.3	19.1	0.66	.42	7.1
Clay	0.4	18.3	22.9	0.79	.50	8.4
Clinton	1.0	49.1	61.4	2.13	1.36	22.8
Coles	1.1	55.8	69.8	2.42	1.54	25.9
Cook	1.8	96.2	120.3	4.17	2.66	44.7
Crawford	0.45	20.1	25.1	0.87	.56	9.4
Cumberland	0.55	21.9	27.4	0.95	.61	10.2
De Kalb	5.1	334.3	417.9	14.48	9.24	155.2
De Witt	0.8	57.9	72.4	2.51	1.60	26.9
Douglas	2.6	152.5	190.6	6.60	4.21	70.7
Du Page	0.9	54.4	68.0	2.36	1.51	25.4
Edgar	1.2	77.6	97.0	3.36	2.14	36.0
Edwards	0.35	15.7	19.6	0.68	.43	7.2
Effingham	0.6	34.0	42.5	1.47	.94	15.8
Fayette	0.95	48.2	60.3	2.09	1.33	22.3
Ford	1.9	100.0	125.0	4.33	2.76	46.4
Franklin	0.35	14.5	18.1	0.63	.40	6.7
Fulton	2.8	139.2	174.0	6.03	3.85	64.7
Gallatin	0.1	3.8	4.8	0.16	.10	1.7
Greene	0.45	21.1	26.4	0.91	.58	9.7
Grundy	1.4	73.4	91.8	3.18	2.03	34.1
Hamilton	0.25	9.9	12.4	0.43	.27	4.5
Hancock	1.9	81.0	101.3	3.51	2.24	37.6
Hardin	0.05	1.9	2.4	0.08	.05	0.8
Henderson	4.4	218.8	273.5	9.47	6.04	101.5
Henry	22.4	1,378.1	1,722.6	59.67	38.07	639.6
Iroquois	4.7	233.1	291.4	10.09	6.44	108.2
Jackson	0.3	12.3	15.4	0.53	.34	5.7
Jasper	0.5	25.4	31.8	1.10	.70	11.8

Table A-4. (contd.)

County	Crop: Acres Harvested for Grain[b] (10^3)	Crop: Production (10^3 Bushels)[b]	Crop: Total Value ($\$10^3$, 1978)	Residue: Residue Dry Tons (10^3)	Residue: "Wasted" Residue Dry Tons (10^3)	Residue: Energy Value of "Wasted" Residues (10^9 Btu)
Jefferson	0.35	15.2	19.0	0.66	.42	7.1
Jersey	0.15	6.6	8.3	0.29	.19	3.2
Jo Daviess	15.2	858.5	1,073.1	37.19	23.7	398.7
Johnson	0.25	8.4	10.5	0.36	.23	3.9
Kane	6.1	356.7	445.9	15.45	9.86	165.6
Kankakee	4.1	234.4	293.0	10.15	6.48	108.9
Kendall	1.8	94.4	118.0	4.09	2.61	43.8
Knox	7.0	426.2	532.8	18.45	11.77	197.7
Lake	2.9	172.5	215.6	7.47	4.77	80.1
La Salle	6.9	379.2	474.0	16.42	10.48	176.1
Lawrence	0.1	4.1	5.1	0.18	.11	1.8
Lee	7.8	452.4	565.5	19.59	12.50	210.0
Livingston	4.1	224.1	280.1	9.70	6.19	104.0
Logan	3.2	202.2	252.8	8.76	5.59	93.9
McDonough	3.0	149.2	186.5	6.46	4.12	69.2
McHenry	8.4	482.8	603.5	20.91	13.34	224.1
McLean	3.9	218.6	273.3	9.47	6.04	101.5
Macon	0.7	44.9	56.1	1.94	1.24	20.8
Macoupin	0.45	22.5	28.1	0.97	.62	10.4
Madison	0.7	35.2	44.0	1.52	.97	16.3
Marion	0.55	24.6	30.8	1.07	.68	11.4
Marshall	2.7	159.6	199.5	6.91	4.41	74.1
Mason	0.3	126.4	158.0	5.47	3.49	58.6
Massac	2.0	11.0	13.8	0.48	.31	5.2
Menard	0.6	37.3	46.6	1.62	1.03	17.3
Mercer	6.6	322.9	403.6	13.98	8.92	149.9
Monroe	0.35	14.7	18.4	0.64	.41	6.9
Montgomery	0.95	47.6	59.5	2.06	1.31	22.0
Morgan	1.0	56.2	70.3	2.43	1.55	26.0
Moultrie	1.4	79.4	99.3	3.44	2.19	36.8
Ogle	12.1	695.6	870.8	30.12	19.22	322.9
Peoria	3.7	196.1	245.1	8.49	5.42	91.1
Perry	0.4	18.4	23.0	0.80	.51	8.6
Piatt	1.6	100.4	125.5	4.35	2.78	46.7
Pike	2.5	102.2	127.8	4.43	2.83	47.5
Pope	0.2	7.7	9.6	0.33	.21	3.5
Pulaski	0.1	3.3	4.1	0.14	.09	1.5
Putnam	0.9	52.6	65.8	2.28	1.45	24.4
Randolph	0.9	36.9	46.1	1.60	1.02	17.1
Richland	0.3	13.4	16.8	0.58	.37	6.2

Table A-4. (contd.)

County	Crop: Acres Harvested for Grain[b] (10^3)	Crop: Production (10^3 Bushels)[b]	Crop: Total Value ($\$10^3$, 1978)	Residue: Residue Dry Tons (10^3)	Residue: "Wasted" Residue Dry Tons (10^3)	Residue: Energy Value of "Wasted" Residues (10^9 Btu)
Rock Island	5.2	299.0	373.8	12.95	8.26	138.8
St. Clair	0.75	34.6	43.3	1.50	.96	16.1
Saline	0.4	14.2	17.8	0.61	.39	6.6
Sangamon	1.0	64.4	80.5	2.79	1.78	29.9
Schuyler	0.7	28.4	35.5	1.23	.78	13.1
Scott	0.2	11.2	14.0	0.48	.31	5.2
Shelby	0.95	46.3	57.9	2.00	1.28	21.5
Stark	2.4	134.5	168.1	5.82	3.71	62.3
Stephenson	15.1	883.3	1,104.1	38.25	24.40	409.9
Tazewell	1.7	109.1	136.4	4.72	3.01	50.6
Union	0.4	13.9	17.4	0.60	.38	6.4
Vermilion	1.6	95.6	119.5	4.14	2.64	44.4
Wabash	0.2	8.9	11.1	0.39	.25	4.2
Warren	7.1	381.9	477.4	16.54	10.55	177.2
Washington	0.3	12.3	15.4	0.53	.34	5.7
Wayne	0.2	9.5	11.9	0.41	.26	4.4
White	0.25	10.9	13.6	0.47	.30	5.0
Whiteside	10.8	653.6	817.0	28.30	18.06	303.4
Will	6.2	256.3	320.4	11.10	7.08	118.9
Williamson	0.2	7.2	9.0	0.31	.20	3.4
Winnebago	7.4	418.0	522.5	18.10	11.55	194.0
Woodford	2.8	185.5	231.9	8.03	5.12	86.0
ILLINOIS	275.0	15,400.0	19,250.0	666.82	425.43	7,147.2

[a]All calculations are made with conversion factors given in Table 3.1.

[b]Illinois Department of Agriculture (1979).

Table A-5. Illinois Sorghum Acreage, Production, Value, Residue, and Residue Btu Content, 1978[a]

	Crop			Residue		
County	Acres Harvested for Grain[b] (10^3)	Production (10^3 Bushels)[b]	Total Value ($\$10^3$, 1978)	Residue Dry Tons (10^3)	"Wasted" Residue Dry Tons (10^3)	Energy Value of "Wasted" Residues (10^9 Btu)
Adams	0.4	25.4	45.5	0.45	0.16	2.69
Alexander	0.8	58.6	104.9	1.03	0.37	6.22
Bond	2.7	197.3	353.2	3.47	1.25	21.00
Boone	0.1	7.0	12.5	0.12	0.04	0.67
Brown	0.1	6.3	11.3	0.11	0.04	0.67
Bureau	0.05	3.7	6.6	0.07	0.03	0.50
Calhoun	0.1	7.0	12.5	0.12	0.04	0.67
Carroll	0.3	19.9	35.6	0.35	0.13	2.18
Cass	0.7	47.2	84.5	0.83	0.30	5.04
Champaign	0.1	7.3	13.1	0.13	0.05	0.84
Christian	0.2	14.7	26.3	0.26	0.09	1.51
Clark	0.6	42.2	75.5	0.74	0.27	4.54
Clay	1.4	92.8	166.1	1.63	0.59	9.91
Clinton	2.9	220.9	395.4	3.89	1.40	23.52
Coles	0.1	7.0	12.5	0.12	0.04	0.67
Cook	0.0	0.0	0.0	0.00	0.00	0.00
Crawford	0.7	47.8	85.6	0.84	0.30	5.04
Cumberland	0.2	13.9	24.9	0.24	0.09	1.51
De Kalb	0.2	14.3	25.6	0.25	0.09	1.51
De Witt	0.1	6.8	12.2	0.12	0.04	0.67
Douglas	0.05	3.6	6.4	0.06	0.02	0.34
Du Page	0.05	3.3	5.9	0.06	0.02	0.34
Edgar	0.15	10.7	19.2	0.19	0.07	1.18
Edwards	1.3	83.3	149.1	1.47	0.53	8.90
Effingham	0.6	38.7	69.3	0.68	0.24	4.03
Fayette	1.8	124.5	222.9	2.19	0.79	13.27
Ford	0.15	10.4	18.6	0.18	0.06	1.01
Franklin	2.2	132.4	237.0	2.33	0.84	14.11
Fulton	0.05	3.2	5.7	0.06	0.02	0.34
Gallatin	0.6	36.9	66.1	0.65	0.23	3.86
Greene	0.2	14.5	26.0	0.26	0.09	1.51
Grundy	0.05	3.3	5.9	0.06	0.02	0.34
Hamilton	2.2	128.0	229.0	2.25	0.81	13.61
Hancock	0.1	6.5	11.6	0.11	0.04	0.67
Hardin	0.05	3.0	5.4	0.05	0.02	0.34
Henderson	0.05	3.6	6.4	0.06	0.02	0.34
Henry	0.05	3.6	6.4	0.06	0.02	0.34
Iroquois	0.15	10.3	18.4	0.18	0.06	1.01
Jackson	1.3	82.5	147.7	1.45	0.52	8.74
Jasper	1.1	75.1	134.4	1.32	0.48	8.06

Table A-5. (contd.)

County	Crop			Residue		
	Acres Harvested for Grain[b] (10^3)	Production (10^3 Bushels)[b]	Total Value ($\$10^3$, 1978)	Residue Dry Tons (10^3)	"Wasted" Residue Dry Tons (10^3)	Energy Value of "Wasted" Residues (10^9 Btu)
Jefferson	1.7	114.0	204.1	2.01	0.72	12.10
Jersey	1.0	68.8	123.2	1.21	0.44	7.39
Jo Daviess	0.1	6.9	12.4	0.12	0.04	0.67
Johnson	3.1	190.7	341.4	3.36	1.21	20.33
Kane	0.05	3.5	6.3	0.06	0.02	0.34
Kankakee	0.1	6.8	12.2	0.12	0.04	0.67
Kendall	0.05	3.2	5.7	0.06	0.02	0.34
Knox	0.05	3.5	6.3	0.06	0.02	0.34
Lake	0.05	3.1	5.5	0.05	0.02	0.34
La Salle	0.05	3.3	5.9	0.06	0.02	0.34
Lawrence	0.3	19.9	35.6	0.35	0.13	2.18
Lee	0.1	7.3	13.1	0.13	0.05	0.84
Livingston	0.1	7.0	12.5	0.12	0.04	0.67
Logan	0.05	3.2	5.7	0.06	0.02	0.34
McDonough	0.05	3.4	6.1	0.06	0.02	0.34
McHenry	0.15	9.8	17.5	0.17	0.06	1.01
McLean	0.05	3.4	6.1	0.06	0.02	0.34
Macon	0.1	6.8	12.2	0.12	0.04	0.67
Macoupin	0.5	36.7	65.7	0.65	0.23	3.86
Madison	1.8	134.0	239.9	2.36	0.85	14.28
Marion	1.5	97.9	175.2	1.72	0.62	10.42
Marshall	0.05	3.2	5.7	0.06	0.02	0.34
Mason	0.2	12.3	22.0	0.22	0.08	1.34
Massac	2.1	145.0	259.6	2.55	0.92	15.46
Menard	0.05	3.3	5.9	0.06	0.02	0.34
Mercer	0.05	3.6	6.4	0.06	0.02	0.34
Monroe	2.4	159.4	285.3	2.81	1.01	16.97
Montgomery	0.4	29.4	52.6	0.52	0.19	3.19
Morgan	0.15	11.2	20.0	0.20	0.07	1.18
Moultrie	0.1	7.1	12.7	0.12	0.04	0.67
Ogle	0.05	3.7	6.6	0.07	0.03	0.50
Peoria	0.05	3.2	5.7	0.06	0.02	0.34
Perry	2.1	133.3	238.6	2.35	0.85	14.28
Piatt	0.05	3.6	6.4	0.06	0.02	0.34
Pike	0.9	63.4	113.5	1.12	0.40	6.72
Pope	1.4	84.2	150.7	1.48	0.53	8.90
Pulaski	5.7	417.4	747.1	7.35	2.65	44.52
Putnam	0.05	3.5	6.3	0.06	0.02	0.34
Randolph	3.0	190.4	340.8	3.35	1.21	20.33
Richland	0.8	53.8	96.3	0.95	0.34	5.71

Table A-5. (contd.)

County	Crop: Acres Harvested for Grain[b] (10^3)	Crop: Production (10^3 Bushels)[b]	Crop: Total Value ($\$10^3$, 1978)	Residue: Residue Dry Tons (10^3)	Residue: "Wasted" Residue Dry Tons (10^3)	Residue: Energy Value of "Wasted" Residues (10^9 Btu)
Rock Island	0.05	3.5	6.3	0.06	0.02	0.34
St. Clair	1.6	112.5	201.4	1.98	0.71	11.93
Saline	0.35	21.1	37.8	0.37	0.13	2.18
Sangamon	0.5	36.7	65.7	0.65	0.23	3.80
Schuyler	0.05	3.1	5.5	0.05	0.02	0.34
Scott	0.15	10.7	19.2	0.19	0.07	1.18
Shelby	0.25	17.8	31.9	0.31	0.11	1.85
Stark	0.0	0.0	0.0	0.00	0.00	0.00
Stephenson	0.2	14.3	25.6	0.25	0.09	1.51
Tazewell	0.05	3.3	5.9	0.06	0.02	0.34
Union	1.8	109.0	195.1	1.92	0.69	11.59
Vermilion	0.1	7.1	12.7	0.12	0.04	0.67
Wabash	0.15	9.9	17.7	0.17	0.06	1.01
Warren	0.05	3.5	6.3	0.06	0.02	0.34
Washington	4.6	350.4	627.2	6.17	2.22	37.30
Wayne	1.7	107.3	192.1	1.89	0.68	11.42
White	1.1	67.3	120.5	1.18	0.42	7.06
Whiteside	0.1	6.9	12.4	0.12	0.04	0.67
Will	0.15	9.5	17.0	0.17	0.06	1.01
Williamson	0.7	41.3	73.9	0.73	0.26	4.37
Winnebago	0.1	7.1	12.7	0.12	0.04	0.67
Woodford	0.0	0.0	0.0	0.00	0.00	0.00
ILLINOIS	68.0	4,624.0	8,277.0	81.38	29.30	492.24

[a]All calculations are made with conversion factors given in Table 3.1.

[b]Illinois Department of Agriculture (1979).

Table A-6. Illinois Barley Acreage, Production, Value, Residue, and Residue Btu Content, 1978[a]

	Crop			Residue		
County	Acres Harvested for Grain[b] (10^3)	Production (10^3 Bushels)[b]	Total Value ($\$10^3$, 1978)	Residue Dry Tons (10^3)	"Wasted" Residue Dry Tons (10^3)	Energy Value of "Wasted" Residues (10^9 Btu)
Adams	0.2	8.3	14.5	0.45	0.38	6.38
Alexander	0.0	0.0	0.0	0.00	0.00	0.00
Bond	0.2	8.0	14.0	0.44	0.37	6.22
Boone	0.15	6.5	11.4	0.35	0.29	4.87
Brown	0.0	0.0	0.0	0.00	0.00	0.00
Bureau	0.05	2.2	3.9	0.12	0.10	1.68
Calhoun	0.05	2.1	3.7	0.11	0.09	1.51
Carroll	0.05	2.0	3.5	0.11	0.09	1.51
Cass	0.1	4.0	7.0	0.22	0.19	3.19
Champaign	0.05	2.2	3.9	0.12	0.10	1.68
Christian	0.05	2.2	3.9	0.12	0.10	1.68
Clark	0.0	0.0	0.0	0.00	0.00	0.00
Clay	0.0	0.0	0.0	0.00	0.00	0.00
Clinton	0.2	8.2	14.4	0.45	0.38	6.38
Coles	0.05	2.1	3.7	0.11	0.09	1.51
Cook	0.1	4.3	7.5	0.23	0.19	3.19
Crawford	0.0	0.0	0.0	0.00	0.00	0.00
Cumberland	0.0	0.0	0.0	0.00	0.00	0.00
De Kalb	0.05	2.3	4.0	0.13	0.11	1.85
De Witt	0.05	2.1	3.7	0.11	0.09	1.51
Douglas	0.05	2.1	3.7	0.11	0.09	1.51
Du Page	0.0	0.0	0.0	0.00	0.00	0.00
Edgar	0.1	4.1	7.2	0.22	0.19	3.19
Edwards	0.2	8.3	14.5	0.45	0.38	6.38
Effingham	0.15	6.0	10.5	0.33	0.28	4.70
Fayette	0.05	2.0	3.5	0.11	0.09	1.51
Ford	0.1	4.0	7.0	0.22	0.19	3.19
Franklin	0.1	4.2	7.4	0.23	0.19	3.19
Fulton	0.3	11.9	20.8	0.65	0.55	9.24
Gallatin	0.0	0.0	0.0	0.00	0.00	0.00
Greene	0.05	2.1	3.7	0.11	0.09	1.51
Grundy	0.0	0.0	0.0	0.00	0.00	0.00
Hamilton	0.1	4.2	7.4	0.23	0.19	3.19
Hancock	0.1	4.0	7.0	0.22	0.19	3.19
Hardin	0.0	0.0	0.0	0.00	0.00	0.00
Henderson	0.0	0.0	0.0	0.00	0.00	0.00
Henry	0.2	8.3	14.5	0.45	0.38	6.38
Iroquois	0.05	2.1	3.7	0.11	0.09	1.51
Jackson	0.1	4.1	7.2	0.22	0.19	3.19
Jasper	0.15	6.1	10.7	0.33	0.28	4.70

Table A-6. (contd.)

	Crop			Residue		
County	Acres Harvested for Grain[b] (10^3)	Production (10^3 Bushels)[b]	Total Value ($\$10^3$, 1978)	Residue Dry Tons (10^3)	"Wasted" Residue Dry Tons (10^3)	Energy Value of "Wasted" Residues (10^9 Btu)
Jefferson	0.05	2.1	3.7	0.11	0.09	1.51
Jersey	0.05	2.1	3.7	0.11	0.09	1.51
Jo Daviess	0.2	8.1	14.2	0.44	0.37	6.22
Johnson	0.05	2.1	3.7	0.11	0.09	1.51
Kane	0.1	4.5	7.9	0.25	0.21	3.53
Kankakee	0.05	2.1	3.7	0.11	0.09	1.51
Kendall	0.05	2.2	3.9	0.12	0.10	1.68
Knox	0.1	4.1	7.2	0.22	0.19	3.19
Lake	0.6	25.8	45.2	1.41	1.19	20.00
La Salle	0.05	2.2	3.9	0.12	0.10	1.68
Lawrence	0.0	0.0	0.0	0.00	0.00	0.00
Lee	0.05	2.2	3.9	2.12	0.10	1.68
Livingston	0.05	2.1	3.7	0.11	0.09	1.51
Logan	0.05	2.1	3.7	0.11	0.09	1.51
McDonough	0.0	0.0	0.0	0.00	0.00	0.00
McHenry	0.3	12.9	22.6	0.70	0.59	9.91
McLean	0.1	4.2	7.4	0.23	0.19	3.19
Macon	0.0	0.0	0.0	0.00	0.00	0.00
Macoupin	0.15	6.3	11.0	0.34	0.29	4.87
Madison	0.15	6.0	10.5	0.33	0.28	4.70
Marion	0.15	5.8	10.2	0.32	0.27	4.54
Marshall	0.05	2.0	3.5	0.11	0.09	1.51
Mason	0.0	0.0	0.0	0.00	0.00	0.00
Massac	0.15	6.4	11.2	0.35	0.29	4.87
Menard	0.05	2.0	3.4	0.11	0.09	1.51
Mercer	0.15	6.4	11.2	0.35	0.29	4.87
Monroe	0.25	10.8	18.9	0.59	0.50	8.40
Montgomery	0.3	12.6	22.1	0.69	0.58	9.74
Morgan	0.1	4.2	7.4	0.23	0.19	3.19
Moultrie	0.0	0.0	0.0	0.00	0.00	0.00
Ogle	0.1	4.3	7.5	0.13	0.19	3.19
Peoria	0.0	0.0	0.0	0.00	0.00	0.00
Perry	0.15	6.2	10.9	0.34	0.29	4.87
Piatt	0.05	2.2	3.9	0.12	0.10	1.68
Pike	0.05	2.0	3.5	0.11	0.09	1.51
Pope	0.05	2.1	3.7	0.11	0.09	1.51
Pulaski	0.1	4.3	7.5	0.23	0.19	3.19
Putnam	0.05	2.1	3.7	0.11	0.09	1.51
Randolph	0.3	13.1	22.9	0.72	0.61	10.25
Richland	0.0	0.0	0.0	0.00	0.00	0.00

Table A-6. (contd.)

County	Crop			Residue		
	Acres Harvested for Grain[b] (10^3)	Production (10^3 Bushels)[b]	Total Value ($\$10^3$, 1978)	Residue Dry Tons (10^3)	"Wasted" Residue Dry Tons (10^3)	Energy Value of "Wasted" Residues (10^9 Btu)
Rock Island	0.0	0.0	0.0	0.00	0.00	0.00
St. Clair	0.2	8.4	14.7	0.46	0.39	6.55
Saline	0.05	2.2	3.9	0.12	0.10	1.68
Sangamon	0.05	2.2	3.9	0.12	0.10	1.68
Schuyler	0.05	2.0	3.5	0.11	0.09	1.51
Scott	0.0	0.0	0.0	0.00	0.00	0.00
Shelby	0.05	2.1	3.7	0.11	0.09	1.51
Stark	0.05	2.1	3.7	0.11	0.09	1.51
Stephenson	0.35	15.4	27.0	0.84	0.71	11.93
Tazewell	0.05	2.0	3.5	0.11	0.09	1.51
Union	0.05	2.2	3.9	0.12	0.10	1.68
Vermilion	0.05	2.2	3.9	0.12	0.10	1.68
Wabash	0.1	4.3	7.5	0.23	0.19	3.19
Warren	0.05	2.0	3.5	0.11	0.09	1.51
Washington	0.1	4.2	7.4	0.23	0.19	3.19
Wayne	0.05	2.1	3.7	0.11	0.09	1.51
White	0.05	2.2	3.9	0.12	0.10	1.68
Whiteside	0.05	2.0	3.5	0.11	0.09	1.51
Will	0.1	4.4	7.7	0.24	0.20	3.36
Williamson	0.1	4.2	7.4	0.23	0.19	3.19
Winnebago	0.1	4.2	7.2	0.23	0.19	3.19
Woodford	0.0	0.0	0.0	0.00	0.00	0.00
ILLINOIS	9.0	378.0	661.5	20.64	17.38	291.98

[a]All calculations are made with conversion factors given in Table 3.1.

[b]Illinois Department of Agriculture (1979).

Table A-7. Illinois Rye Acreage, Production, Value, Residue, and Residue Btu Content, 1978[a]

	Crop			Residue		
County	Acres Harvested for Grain[b] (10^3)	Production (10^3 Bushels)[b]	Total Value (\$$10^3$, 1978)	Residue Dry Tons (10^3)	"Wasted" Residue Dry Tons (10^3)	Energy Value of "Wasted" Residues (10^9 Btu)
Adams	0.2	4.7	10.8	0.24	0.20	3.36
Alexander	0.0	0.0	0.0	0.00	0.00	0.00
Bond	0.1	2.2	5.1	0.11	0.09	1.51
Boone	0.1	2.5	5.8	0.13	0.11	1.85
Brown	0.15	3.4	7.8	0.17	0.14	2.35
Bureau	0.05	1.1	2.5	0.06	0.06	0.84
Calhoun	0.1	2.2	5.1	0.11	0.09	1.51
Carroll	0.3	7.4	17.0	0.37	0.31	5.21
Cass	0.7	14.7	33.8	0.74	0.62	10.42
Champaign	0.05	1.1	2.5	0.06	0.05	0.84
Christian	0.1	2.3	5.3	0.12	0.10	1.68
Clark	0.05	1.1	2.5	0.06	0.05	0.84
Clay	0.05	1.1	2.5	0.06	0.05	0.84
Clinton	0.0	0.0	0.0	0.00	0.00	0.00
Coles	0.05	1.1	2.5	0.06	0.05	0.84
Cook	0.0	0.0	0.0	0.00	0.00	0.00
Crawford	0.05	1.1	2.5	0.06	0.05	0.84
Cumberland	0.1	2.3	5.3	0.12	0.10	1.68
De Kalb	0.05	1.3	3.0	0.07	0.06	1.01
De Witt	0.05	1.1	2.5	0.06	0.05	0.84
Douglas	0.0	0.0	0.0	0.00	0.00	0.00
Du Page	0.0	0.0	0.0	0.00	0.00	0.00
Edgar	0.05	1.1	2.5	0.06	0.05	0.84
Edwards	0.15	3.3	7.6	0.17	0.14	2.35
Effingham	0.05	1.1	2.5	0.06	0.05	0.84
Fayette	0.6	14.6	33.6	0.74	0.62	10.42
Ford	0.05	1.0	2.3	0.05	0.04	0.67
Franklin	0.05	1.1	2.5	0.06	0.05	0.84
Fulton	0.1	2.5	5.8	0.13	0.11	1.85
Gallatin	0.0	0.0	0.0	0.00	0.00	0.00
Greene	0.2	4.9	11.3	0.25	0.21	3.53
Grundy	0.0	0.0	0.0	0.00	0.00	0.00
Hamilton	0.2	4.4	10.1	0.22	0.19	3.19
Hancock	0.1	2.3	5.3	0.12	0.10	1.68
Hardin	0.0	0.0	0.0	0.00	0.00	0.00
Henderson	0.25	5.3	12.2	0.27	0.23	3.86
Henry	0.2	4.4	10.1	0.22	0.19	3.19
Iroquois	0.1	2.0	4.6	0.10	0.08	1.34
Jackson	0.2	4.2	9.7	0.21	0.18	3.02
Jasper	0.4	8.8	20.2	0.44	0.37	6.22

Table A-7. (contd.)

County	Crop: Acres Harvested for Grain[b] (10^3)	Crop: Production (10^3 Bushels)[b]	Crop: Total Value ($\$10^3$, 1978)	Residue: Residue Dry Tons (10^3)	Residue: "Wasted" Residue Dry Tons (10^3)	Residue: Energy Value of "Wasted" Residues (10^9 Btu)
Jefferson	0.05	1.1	2.5	0.06	0.05	0.84
Jersey	0.3	7.3	16.8	0.37	0.31	5.21
Jo Daviess	0.15	3.3	7.6	0.17	0.14	2.35
Johnson	0.05	1.0	2.3	0.05	0.04	0.67
Kane	0.05	1.2	2.8	0.06	0.05	0.84
Kankakee	0.2	4.1	9.4	0.21	0.18	3.02
Kendall	0.05	1.2	2.8	0.06	0.05	0.84
Knox	0.05	1.2	2.8	0.06	0.05	0.84
Lake	0.05	1.1	2.5	0.06	0.05	0.84
La Salle	0.1	2.3	5.3	0.12	0.10	1.68
Lawrence	0.0	0.0	0.0	0.00	0.00	0.00
Lee	0.1	2.3	5.3	0.12	0.10	1.68
Livingston	0.1	2.2	5.1	0.11	0.09	1.51
Logan	0.05	1.1	2.5	0.06	0.05	0.84
McDonough	0.05	1.2	2.8	0.06	0.05	0.84
McHenry	0.05	1.2	2.8	0.06	0.05	0.84
McLean	0.05	1.1	2.5	0.06	0.05	0.84
Macon	0.1	2.2	5.1	0.11	0.09	1.51
Macoupin	0.35	8.9	20.5	0.45	0.38	6.38
Madison	0.35	8.2	18.9	0.41	0.35	5.88
Marion	0.2	4.4	10.1	0.22	0.19	3.19
Marshall	0.05	1.1	2.5	0.06	0.05	0.84
Mason	3.0	57.8	132.9	2.91	2.45	41.16
Massac	0.0	0.0	0.0	0.00	0.00	0.00
Menard	0.05	1.1	2.5	0.06	0.05	0.84
Mercer	0.15	3.3	7.6	0.17	0.14	2.35
Monroe	0.05	1.1	2.5	0.06	0.05	0.84
Montgomery	0.4	9.3	21.4	0.47	0.40	6.72
Morgan	0.1	2.4	5.5	0.12	0.10	1.68
Moultrie	0.0	0.0	0.0	0.00	0.00	0.00
Ogle	0.1	2.5	5.8	0.13	0.11	1.85
Peoria	0.05	1.1	2.5	0.06	0.05	0.84
Perry	0.0	0.0	0.0	0.00	0.00	0.00
Piatt	0.05	1.1	2.5	0.06	0.05	0.84
Pike	0.2	4.3	9.9	0.22	0.19	3.19
Pope	0.05	1.0	2.3	0.05	0.04	0.67
Pulaski	0.05	1.0	2.3	0.05	0.04	0.67
Putnam	0.05	1.1	2.5	0.06	0.05	0.84
Randolph	0.4	9.0	20.7	0.45	0.38	6.38
Richland	0.05	1.1	2.5	0.06	0.05	0.84

Table A-7. (contd.)

County	Crop: Acres Harvested for Grain[b] (10^3)	Crop: Production (10^3 Bushels)[b]	Crop: Total Value (\$$10^3$, 1978)	Residue: Residue Dry Tons (10^3)	Residue: "Wasted" Residue Dry Tons (10^3)	Residue: Energy Value of "Wasted" Residues (10^9 Btu)
Rock Island	0.2	4.2	9.7	0.21	0.18	3.02
St. Clair	0.25	5.7	13.1	0.29	0.24	4.03
Saline	0.15	3.3	7.6	0.17	0.14	2.35
Sangamon	0.05	1.2	2.8	0.06	0.05	0.84
Schuyler	0.05	1.1	2.5	0.06	0.05	0.84
Scott	0.1	2.3	5.3	0.12	0.10	1.68
Shelby	0.05	1.1	2.5	0.06	0.05	0.84
Stark	0.05	1.1	2.5	0.06	0.05	0.84
Stephenson	0.1	2.4	5.5	0.12	0.10	1.68
Tazewell	0.5	10.9	25.1	0.55	0.46	7.73
Union	0.05	1.0	2.3	0.05	0.04	0.67
Vermilion	0.15	3.1	7.1	0.16	0.13	2.18
Wabash	0.1	2.2	5.1	0.11	0.09	1.51
Warren	0.05	1.2	2.8	0.06	0.05	0.84
Washington	0.1	2.3	5.3	0.12	0.10	1.68
Wayne	0.1	2.1	4.8	0.11	0.09	1.51
White	0.15	3.4	7.8	0.17	0.14	2.35
Whiteside	0.3	6.9	15.9	0.35	0.29	4.87
Will	0.15	3.5	8.1	0.18	0.15	2.52
Williamson	0.05	1.0	2.3	0.05	0.04	0.67
Winnebago	0.1	2.3	5.3	0.12	0.10	1.68
Woodford	0.05	1.1	2.5	0.05	0.05	0.84
ILLINOIS	15.0	330.0	759.0	16.63	14.00	235.20

[a]All calculations are made with conversion factors given in Table 3.1.
[b]Illinois Department of Agriculture 1979).

Table A-8. Milk Cows, Milk Production, and Value, 1978 by Illinois County

County	Number of Milk Cows	Production Per Cow (lb)	Total Production (10^6 lb)	Total Value ($\$10^3$)
Adams	3,300	9,367	30.9	3,214
Alexander	100	10,942	1.1	114
Bond	3,500	10,366	36.3	3,775
Boone	7,000	10,410	72.9	7,582
Brown	200	9,367	1.9	198
Bureau	1,600	10,305	16.5	1,716
Calhoun	200	10,366	2.1	218
Carroll	6,700	10,305	69.0	7,176
Cass	100	10,366	1.0	104
Champaign	600	10,732	6.4	665
Christian	300	10,366	3.1	322
Clark	600	10,308	6.2	645
Clay	600	10,308	6.2	645
Clinton	16,400	10,942	179.5	18,668
Coles	400	10,308	4.1	426
Cook	200	10,410	2.1	218
Crawford	500	10,308	5.2	541
Cumberland	1,500	10,308	15.5	1,612
De Kalb	1,800	10,410	18.7	1,945
De Witt	300	9,896	3.0	312
Douglas	1,200	10,308	12.4	1,270
Du Page	200	10,410	2.1	218
Edgar	500	10,308	5.2	541
Edwards	200	10,300	2.1	218
Effingham	7,000	10,308	72.2	7,509
Fayette	2,100	10,308	21.6	2,246
Ford	400	10,732	4.3	447
Franklin	400	10,300	4.1	426
Fulton	500	9,367	4.7	489
Gallatin	100	10,300	1.0	104
Greene	900	10,366	9.3	967
Grundy	700	10,410	7.3	759
Hamilton	200	10,300	2.1	218
Hancock	900	9,367	8.4	874
Hardin	100	10,300	1.0	104
Henderson	300	9,367	2.8	291
Henry	2,200	10,305	22.7	2,361
Iroquois	4,000	10,732	43.0	4,472
Jackson	1,100	10,942	12.0	1,248
Jasper	2,100	10,308	21.6	2,246

Table A-8. (contd.)

County	Number of Milk Cows	Production Per Cow (lb)	Total Production (10^6 lb)	Total Value ($\$10^3$)
Jefferson	700	10,300	7.2	749
Jersey	1,300	10,366	13.5	1,404
Jo Daviess	21,100	10,305	217.4	22,610
Johnson	400	10,942	4.4	458
Kane	7,400	10,410	77.0	8.008
Kankakee	1,900	10,732	20.4	2,122
Kendall	600	10,410	6.2	645
Knox	1,400	9,367	13.1	1,362
Lake	1,700	10,410	17.7	1,841
La Salle	2,100	10,410	21.9	2,278
Lawrence	400	10,308	4.1	426
Lee	2,200	10,305	22.7	2,361
Livingston	1,500	10,732	16.1	1,674
Logan	400	9,896	4.0	416
McDonough	600	9,367	5.6	582
McHenry	15,200	10,410	158.2	16,453
McLean	1,500	9,986	14.7	1,529
Macon	200	9,896	2.0	208
Macoupin	2,400	10,366	24.9	2,590
Madison	5,000	10,366	51.8	5,387
Marion	1,400	10,308	14.4	1,498
Marshall	400	9,896	4.0	416
Mason	200	9,896	2.0	208
Massac	400	10,300	4.1	426
Menard	100	9,896	1.0	104
Mercer	600	10,305	6.2	645
Monroe	1,100	10,942	12.0	1,248
Montgomery	2,100	10,366	21.8	267
Morgan	300	10,366	3.1	322
Moultrie	700	10,308	7.2	749
Ogle	7,300	10,305	75.2	7,821
Peoria	800	9,896	7.7	822
Perry	1,000	10,942	10.9	1,134
Piatt	300	10,732	3.2	333
Pike	800	10,366	8.3	863
Pope	100	10,300	1.0	104
Pulaski	300	10,942	3.3	343
Putnam	300	10,305	3.1	322
Randolph	3,700	10,942	40.5	4,212
Richland	700	10,308	7.2	749

Table A-8. (contd.)

County	Number of Milk Cows	Production Per Cow (lb)	Total Production (10^6 lb)	Total Value ($\$10^3$)
Rock Island	1,200	10,305	12.4	1,290
St. Clair	3,100	10,942	33.9	3,526
Saline	100	10,300	1.0	104
Sangamon	500	10,366	5.2	541
Schuyler	200	9,367	1.9	198
Scott	100	10,366	1.0	104
Shelby	2,400	10,308	24.7	2,569
Stark	600	9,896	5.9	614
Stephenson	32,500	10,305	334.9	34,830
Tazewell	1,000	9,896	9.9	1,030
Union	700	10,942	7.7	801
Vermilion	1,000	10,732	10.7	1,113
Wabash	300	10,300	3.1	322
Warren	500	9,367	4.7	489
Washington	8,200	10,942	89.7	9,329
Wayne	1,100	10,300	11.4	1,186
White	300	10,300	3.1	322
Whiteside	4,300	10,305	44.3	4,607
Will	3,100	10,410	32.3	3,359
Williamson	400	10,942	4.4	458
Winnebago	6,600	10,305	68.0	7,072
Woodford	1,200	9,896	11.9	1,238
ILLINOIS	231,000	10,403	2,403.0	249,912

[a]All calculations are made with conversion factors given in Table 3.1.
[b]Illinois Department of Agriculture (1979).

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